

RSALOP

Radionuclide Soil Action Levels Oversight Panel

Radiation Detection & Instrumentation Workshop

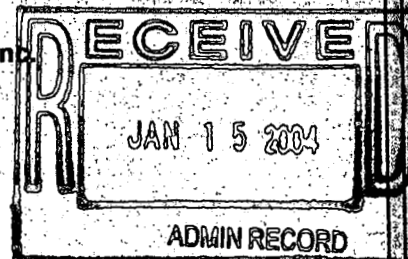
August 12, 1999

Compiled by:

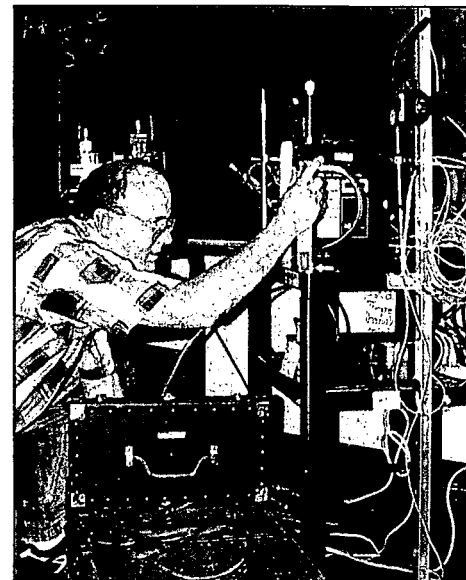


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1998/1999/2000



Radiation and Indoor Environments National Laboratory



The Radiation and Indoor Environments National Laboratory (R&IE) is one of the Environmental Protection Agency's (EPA) two national Laboratories within the Office of Radiation and Indoor Air (ORIA). Our mission is to protect the public and the environment by minimizing exposure to radiation and indoor air pollution through environmental measurements, applied technologies, and education.

This Laboratory is dedicated to being a center of excellence in healthy environments by providing innovative technology and services in the areas of:

- ❖ **Indoor Environments**
- ❖ **Environmental Restoration**
- ❖ **Radioactive Waste Management**
- ❖ **Radiological Emergency Response**
- ❖ **Radioanalysis and Quality Assurance**

R&IE specializes in development, demonstration and employment of technologies in field applications. We provide scientific and technical leadership to EPA headquarters and regional programs, Federal Agencies, State and local governments, and private industries. R&IE manages multi-disciplinary teams with broad ranges of expertise in health physics, physical sciences, chemistry, environmental sciences, engineering, and administrative support. The cooperative interaction between our environmental specialists in the field and scientists in the laboratory assures thorough management from sample collection through analysis and data interpretation. These teams operate state-of-the-art fixed and mobile laboratories, monitoring vehicles, and an extensive collection of calibrated field instrumentation.

Fundamental to R&IE's mission is our commitment in developing and applying innovative, efficient, effective, and practical solutions to ensure public health and environmental quality. R&IE will work closely with you to design and deliver quality laboratory services specifically to meet your needs. For further information, please call (702) 798-2476 or FAX R&IE at (702) 798-2465.

Shown in the pictures above are: left to right, Center for Radioanalysis and Quality Assurance; Center for Environmental Restoration, Monitoring, and Emergency Response; and Center for Indoor Environments.



Center for Environmental Restoration, Monitoring and Emergency Response

The Center for Environmental Restoration, Monitoring, and Emergency Response (CERMER) measures and monitors the concentration, distribution, and environmental transport of radioactive materials. The Center's goal is to *protect public health and the environment through monitoring of environmental radiation exposure*. Teams are prepared to assess sites throughout the country using a variety of techniques. The Center works cooperatively with laboratory scientists to provide efficient and accurate analysis of radionuclides.

Environmental Restoration

CERMER can provide on-site support for site assessment and characterization. The Laboratory's unique fleet of mobile radiological laboratories and support vehicles provides sample collection, analyses, and comprehensive cleanup support activities.

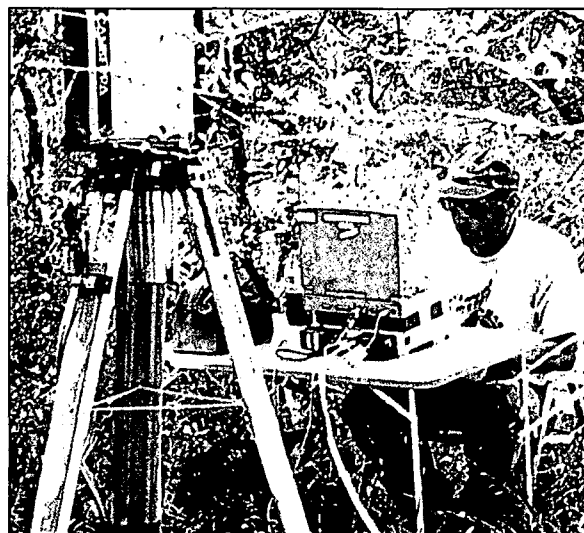
Environmental scientists recommend methods for the remediation of contaminated radiation sites throughout the United States. They apply their knowledge and skill to each individual site for effective restoration. CERMER provides assistance to EPA's Superfund and RCRA programs, Department of Energy, and Department of Defense.

Members of the Center have provided expertise in the development of a Multi-Agency Radiation Survey and Site Investigation Manual. This manual is a federal guidance document for investigating, characterizing, and remediating radioactive material in the environment.

Environmental Monitoring

CERMER conducts air, water, vegetation, and soil surveillance studies as preventive and protective measures for public health and safety.

Environmental scientists perform ambient air sampling to deep water well monitoring, managing fixed and mobile detection instruments, to assess radioactivity. Satellite communication and geographic information systems (GIS) assist center scientists in detecting radioactive pollutants.



Shown in the pictures above are: top to bottom, preparing for an emergency response exercise; collecting in-situ gamma-ray measurements; water sampling.

Emergency Preparedness and Response

CERMER is prepared to respond to potential emergencies regarding radiation by activating a team of experienced specialists. Teams assess environmental impacts to determine the likelihood and extent of radiation exposure. They develop and practice effective strategies for dealing with potential emergency situations. The Mobile Environmental Radiation Laboratory is certified as air transportable, making it available within hours of notification of need.

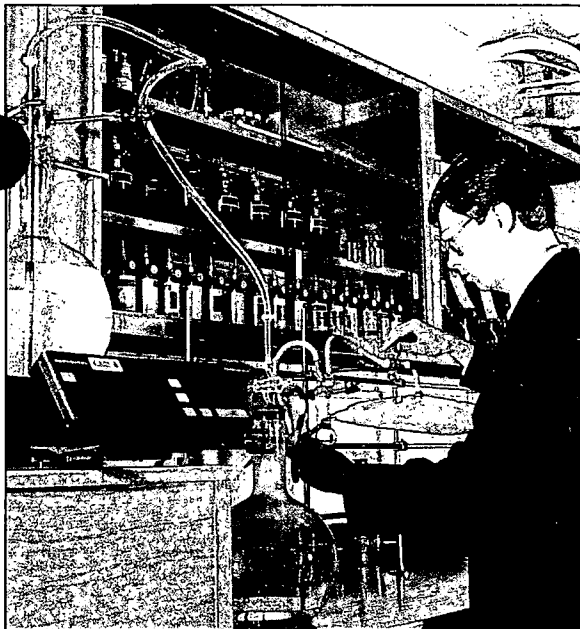
The Mobile Environmental Radiation Laboratory and the support vehicles offer:

- ❖ State-of-the-art radiation monitoring and analytical equipment
- ❖ Air transportable certification
- ❖ Fast deployment

CERMER is dedicated to protect and inform the public of possible migration of radionuclides by providing prompt cost-effective services. For further information please call (702) 798-2469.



Shown in the pictures above are: top right, core sampling; bottom left, performing maintenance on field equipment; bottom right, calibrating a beta instrument in the calibration laboratory.



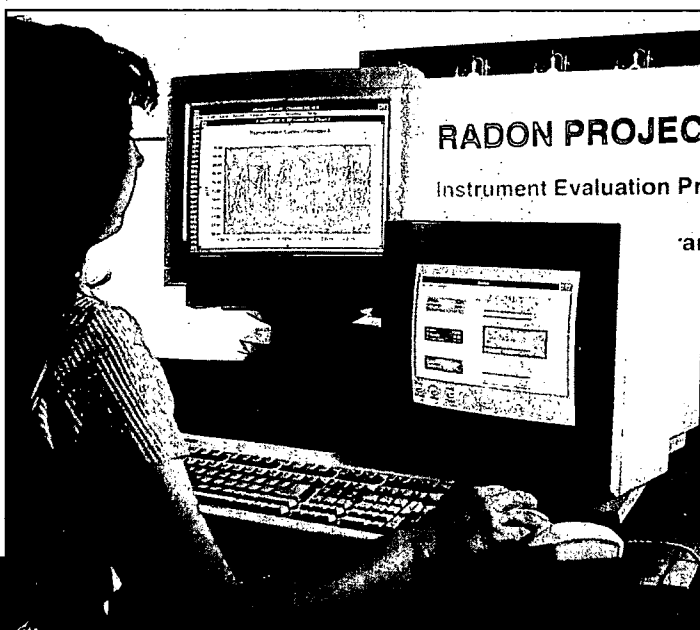
Radon

CIE works with EPA's National Radon Program to educate and help protect the public from radon, a naturally occurring radioactive gas. CIE maintains an internationally recognized radon laboratory that provides technical support and quality assurance to Regions, States, cooperative partners and the radon industry as well as serving as a technical support laboratory for the International Atomic Energy Agency's Radon Metrology Program. The CIE Radon Laboratory operates three state-of-the-art radon calibration chambers capable of providing static environmental conditions or variable "real world" conditions. In addition, CIE has a charcoal canister and electret-ion chamber counting laboratory for radon measurement. CIE's Radon Laboratory maintains traceability to the National Institute of Standards and Technology (NIST).

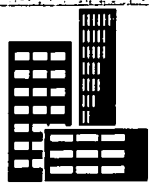
Computer Support

The Center also includes a team of computer specialists on staff to provide software support in database design, programming, and management. CIE computer scientists are continually designing and enhancing computer capabilities to support R&IE's field and laboratory expertise of assessing radioactive localities and concentrations.

CIE is dedicated to developing and demonstrating affordable, effective, energy efficient, and technologically sound services to improve air quality. For further information, please call (702) 798-2340.



5 Shown in the pictures above are: top left, performing radon gas calibration; bottom left, programming computer-controlled environmental chambers; bottom right, bioaerosol sampling in a classroom.



Center for Indoor Environments

The Center for Indoor Environments (CIE) promotes human comfort and productivity through management of air quality in indoor environments. Its goal is to *ensure safe, healthy, and productive indoor environments.*

Indoor Environments

CIE specializes in conducting assessments of indoor environments and building systems using EPA's Building Assessment Survey and Evaluation (BASE) protocols. The Center's scientists work with state-of-the-art equipment and mobile technology to monitor indoor environments and to promote air quality improvements. For example, CIE works in partnership with private industry to retrofit schools with energy efficient ventilation upgrades at low or no cost. CIE also provides technical support to several EPA national programs that study baseline indoor air quality of large buildings and schools.

CIE capabilities include the ability to detect and measure the following:

INDOOR POLLUTANTS

- ❖ Radon
- ❖ Carbon Monoxide
- ❖ Formaldehyde
- ❖ Bioaerosols
- ❖ Respirable Particulates
- ❖ Volatile Organic Compounds

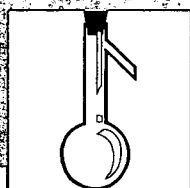
COMFORT FACTORS

- ❖ Temperature
- ❖ Relative Humidity
- ❖ Ventilation Rates
- ❖ Carbon Dioxide
- ❖ Sound & Light

CIE members work together with teachers and students to foster healthy learning environments by promoting proper school classroom ventilation. Such studies as carbon dioxide measurements and measurements of indoor temperatures are conducted to assess classroom indoor air quality.



Shown in the pictures above are: top to bottom, setting up a portable meteorological station; monitoring air quality in a classroom; radon analysis of charcoal canisters.



Center for Radioanalysis and Quality Assurance

The Center for Radioanalysis and Quality Assurance (CRQA) performs analysis of monitoring and sampling data. The Center's mission is to provide accurate analysis of radionuclides in environmental surveillance samples and demonstrate safe management of waste disposal.

Radioanalysis

CRQA offers laboratory assistance in the detection of low-level radiation. CRQA scientists thoroughly investigate environmental collection samples such as water, soil, sediments, air filters, ashed biological materials, and vegetation. The Center's scientists activate an array of samplers and counters to analyze environmental samples either on-site within our mobile radiological sample preparation laboratories or in our fixed analytical laboratory.

CRQA operates a comprehensive analytical laboratory specializing in:

- ❖ Low-level radiochemistry
- ❖ High resolution alpha and gamma spectroscopy
- ❖ Liquid scintillation analysis
- ❖ Thermoluminescent dosimetry

Strictest quality assurance standards are applied to all analyses in the laboratory. CRQA maintains a close relationship with field monitoring personnel for rapid, carefully controlled processing of samples from collection through analysis and documentation. CRQA applies advanced computer support in sample tracking and data management to ensure complete and concise radiation data.

CRQA is accredited by the National Voluntary Laboratory Accreditation Program (NVLAP) as a processor of personnel thermoluminescent dosimetry. CRQA participates in external quality assurance intercomparison programs such as the EPA Radiation Quality Assurance Program (RADQA). All radioanalytical instrument calibration standards are traceable to the National Institute of Standards and Technology (NIST) to ensure that all analytical equipment functions with accuracy.



Shown in the pictures above are: top to bottom, performing microwave digestion of environmental samples; loading samples for tritium analysis; reading thermoluminescent dosimeters.

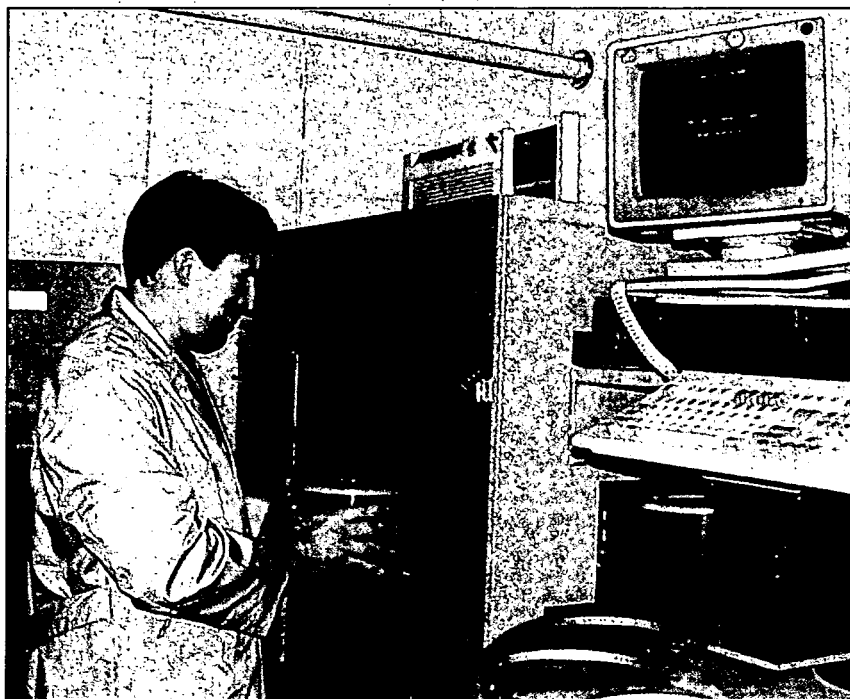
Quality Assurance and Waste Management

CRQA shares ORIA's responsibility for regulating many of Department of Energy (DOE) nuclear waste activities such as the Waste Isolation Pilot Plant in New Mexico. CRQA performs oversight of DOE's waste characterization data to assess completeness and compliance with applicable quality assurance requirements. CRQA works cooperatively with its customers to protect present and future generations from the risks posed by radioactive waste.

With thorough knowledge of waste management, center experts can review and verify:

- ❖ **Repository design and site characterization**
- ❖ **Safe waste storage and management**
- ❖ **Controlled migration of radionuclides**

CRQA is dedicated to providing accurate identification and quantification of environmental pollutants and assisting customers in meeting current and anticipated radioanalytical and waste management requirements. For further information please call (702) 798-2151.



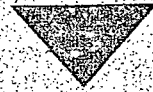
8 Shown in the pictures above are: top right, processing field samples as they arrive at the laboratory; bottom left, preparing samples for gamma analysis; bottom right, performing sample preparation in the mobile laboratory.

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| DENNIS FARMER | US EPA | 702-798 2161 | 702-798 2109 | farmer.dennis@epa.gov |
| Kathleen Meyer | RAC | 970 229 0828 | 970 229 0829 | Kmeyer@verinet.com |
| John Till | RAC | 803 536 4883 | 803 534 1995 | JohnTill@mintspring.com |



RSALOP Workshop



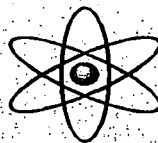
Radiation Detection & Instrumentation

August 12, 1999 - 12:30 - 3:30 p.m.

Broomfield City Building

AGENDA

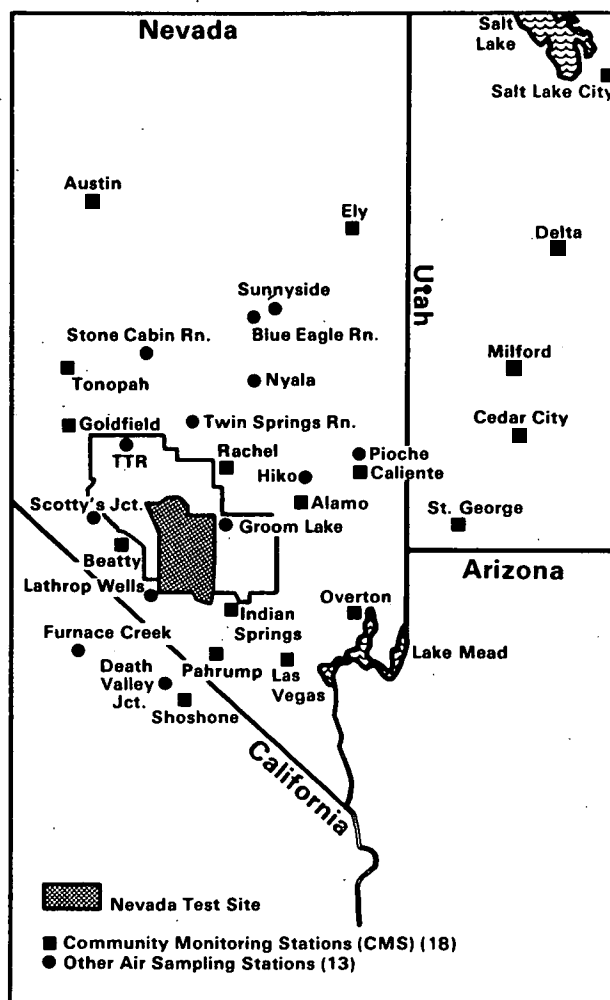
| | | |
|---------------|---------------------------------|--|
| 12:30 - 12:45 | Welcome/Introduction | RSALOP Co-Chairs Tim Rehder, EPA |
| 12:45 - 1:30 | 903 Pad Characterization | Larry Umbaugh, Canberra Industries |
| 1:30 - 2:15 | Challenges of Pu Monitoring | Dennis Farmer U.S. EPA - Radiation and Indoor Environments Natl Lab Las Vegas, NV |
| 2:15 - 2:30 | BREAK | |
| 2:30 - 3:00 | Use of the FIDLR | Bates Estabrooks Kaiser-Hill |
| 3:00 - 3:30 | Actinide Migration Panel Update | Dave Shelton Kaiser-Hill |





Community Radiation Monitoring Program

Figure 1. Community Radiation Monitoring Stations near the Nevada Test Site.



In 1981 a significant change was made in the extensive radiation monitoring networks the U.S. Environmental Protection Agency (EPA), and before that the U.S. Public Health Service, had been operating since 1962 in the communities and ranches surrounding the Nevada Test Site. That summer local residents began managing a new kind of monitoring station in 15 off-site communities. This network of citizen-operated stations that detect and measure radioactivity in the environment was increased to 18 stations in early 1988.

This Community Monitoring Network is a cooperative project of the EPA, the U.S. Department of Energy (DOE), the Desert Research Institute (DRI) of the University of Nevada, the University of Utah, and the sixteen communities. It is an integral part of the Offsite Radiation Safety Program the EPA's Environmental Monitoring Systems Laboratory in Las Vegas has been conducting around the Nevada Test Site for over 30 years.

The DOE sponsors the program and provides the equipment for the stations. EPA's Las Vegas Laboratory provides technical direction, maintains the equipment, analyzes the samples collected, interprets and reports the data. The DRI manages the network, employs

the local station managers, and provides quality assurance checks of the data and the University of Utah provides continuing training.

In each community the EPA and DRI worked with civic leaders to select and hire a local station manager and an alternate. Whenever possible, they chose residents with some scientific training - a science teacher for example. The managers and their alternates were given 2 weeks of intensive training at the University of Utah in Salt Lake City in the summer of 1981. They learned the fundamentals of measuring radiation and the basics of radiation biology. They also learned how to use and care for the equipment at their stations and how to interpret the data they provide. Each summer the station managers attend a 1 week refresher course arranged by the University of Utah.

The EPA's Las Vegas Laboratory selected three kinds of air samplers, a dosimeter (TLD), an exposure rate recorder, and a recording barometer to be operated at each station. The equipment and what it measures is described in Figure 2, and a typical station is illustrated in Figure 3. Because the equipment is operated by electricity, the stations are set up in a public building where electric power is available. All locations provide easy access for residents to observe the equipment in operation and to see the radiation levels as they are recorded.

The local managers have several duties. They check the equipment daily, change filters in the air sampler at prescribed times, check the gamma rate recorder chart for abnormal variations and report these immediately to the DRI and EPA. They also serve as a liaison between their communities and the nuclear testing organization. During the first year of operation, the managers helped to arrange "town hall meetings" in 13 of the communities, where test organization officials briefed residents on the testing program and related safety programs (of which the Community Monitoring Network is a part) and responded to questions and concerns expressed by citizens who attended. In subsequent years, the town hall meetings have been extended to other communities and repeated in most communities to provide updated information.

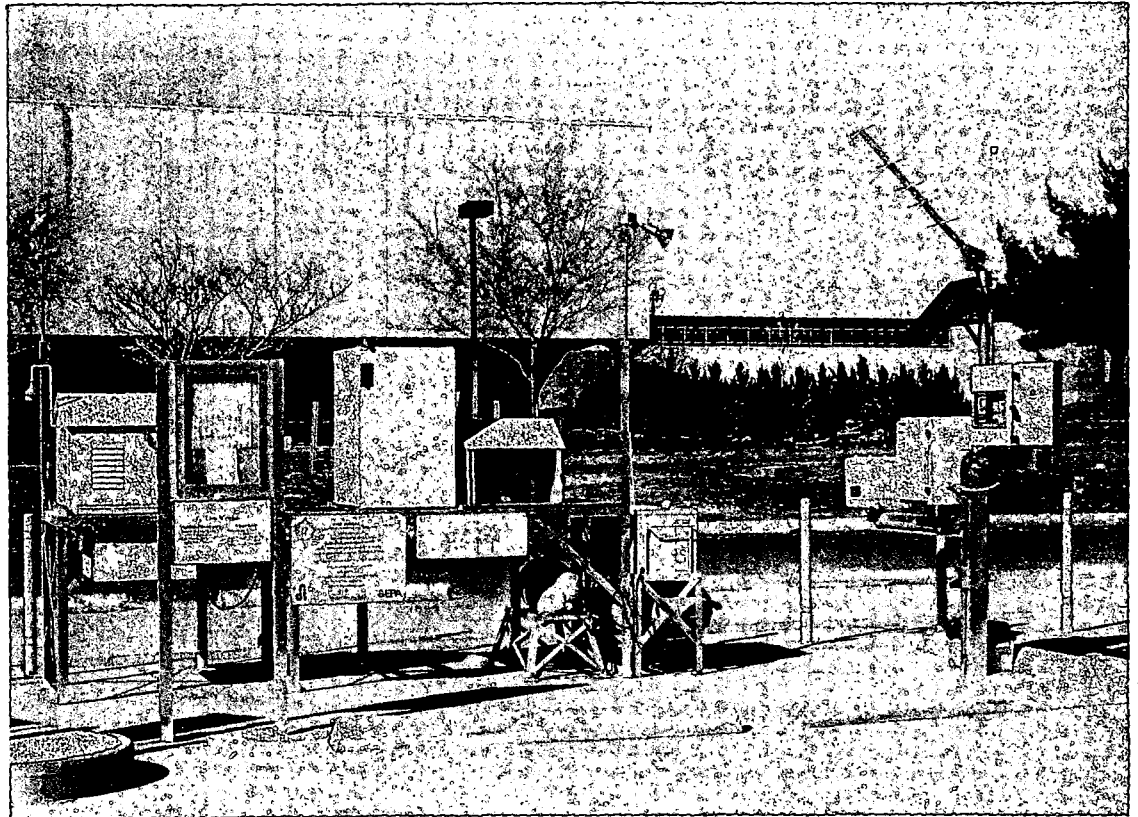
Figure 2. Monitoring equipment at citizen operated stations.

| | |
|---|---|
| Noble gas sampler | Compresses air in a tank. The air sample is analyzed in a laboratory to measure the concentration in air of such radioactive noble (nonreactive) gases as xenon and krypton. |
| Tritium sampler | Collects moisture from the air passing through it. The moisture is analyzed in a laboratory to measure the concentration in air of tritium, the radioactive form of hydrogen. |
| Particulates and reactive gasses sampler | Pulls 2 cubic feet of air per minute through a paper filter and then through a canister of activated charcoal. The paper filter collects particles and the charcoal collects reactive gasses, like iodine. Both are analyzed for radioactivity in a laboratory. |
| Thermoluminescent dosimeter (TLD) | A very small device made of a material that is changed by the gamma radiation it absorbs. When heated (thermo-) in a special laboratory instrument, the TLD releases absorbed energy in the form of light (-luminescent). The intensity of the light is proportional to the gamma radiation absorbed so the total gamma radiation exposure can be calculated. |
| Gamma radiation exposure rate recorder | A pressurized chamber (PIC) detector for gamma radiation is connected to a recorder so that a continuous record of the gamma radiation is obtained, and changes in the normal gamma radiation level are easily seen. It displays the instantaneous reading and records them on a paper strip chart visible to an observer and on a magnetic tape that can be analyzed by a computer. Every 4 hours data are sent through the GEOS satellite system to Las Vegas and the Nevada Test Site. Any radiation readings that exceed a predetermined threshold value are telemetered immediately. |
| Microbarograph | A recording barometer that measures and records barometric pressure. The data are useful in interpreting the gamma radiation exposure rate records, because at lower atmospheric pressures more naturally occurring radioactive gasses, like radon and thoron, are released from the earth's surface and their radioactive decay products contribute to the radiation exposure. |

Technicians from EPA's Las Vegas Laboratory visit the stations each week to inspect the equipment, perform the necessary maintenance, and collect the samples and raw data. All the samples undergo chemical analysis for radionuclides at the Laboratory, and the data are analyzed both by EPA and by the DRI. Each week the technicians deliver to each station a summary statement of results of the analyses from the previous week. The summary statements are displayed at the stations.

The DRI publishes periodic monitoring reports and distributes them widely throughout the communities where the monitoring stations are located. The reports provide interpretive summaries commenting on average values for each station and for the network as a whole and on any deviations from the expected range of values. In the annual report of its environmental radiation monitoring activities, the EPA Laboratory includes analytical data from the community monitoring network and an interpretation of results.

Figure 3. Radiation Monitoring Station at the University of Nevada at Las Vegas



A typical monitoring station is illustrated in Figure 3. Each station is lighted at night, and each has a sign displaying the name and telephone number of the local manager and one that identifies each piece of equipment.

The impetus for the community radiation monitoring program was provided by the success of a similar program instituted in the area surrounding the Three Mile Island nuclear reactor power plant in Pennsylvania. While radioactive krypton was being vented from the reactor that was damaged in a March 1979 accident, local citizens operated community monitoring stations. Their participation in this monitoring program allowed the residents to independently verify the information being released by the government and by power plant officials and thereby provided reassurance to the community at large.

The Las Vegas Lab has been responsible for monitoring the environment surrounding the Test Site since 1954 to detect and measure any radioactivity that might be released to public areas from nuclear tests. The Laboratory's continuing monitoring program is a comprehensive one designed to evaluate the contribution of the underground nuclear testing program to man's radiation exposure.

Figure 4. Sample collection from a Tritium Sampler



Figure 5. Data from the Gamma Radiation Exposure Rate Recorder is transmitted through the GOES Satellite System to Las Vegas and the Nevada Test Site



Figure 6. Collecting a sample from a Noble Gas Sampler



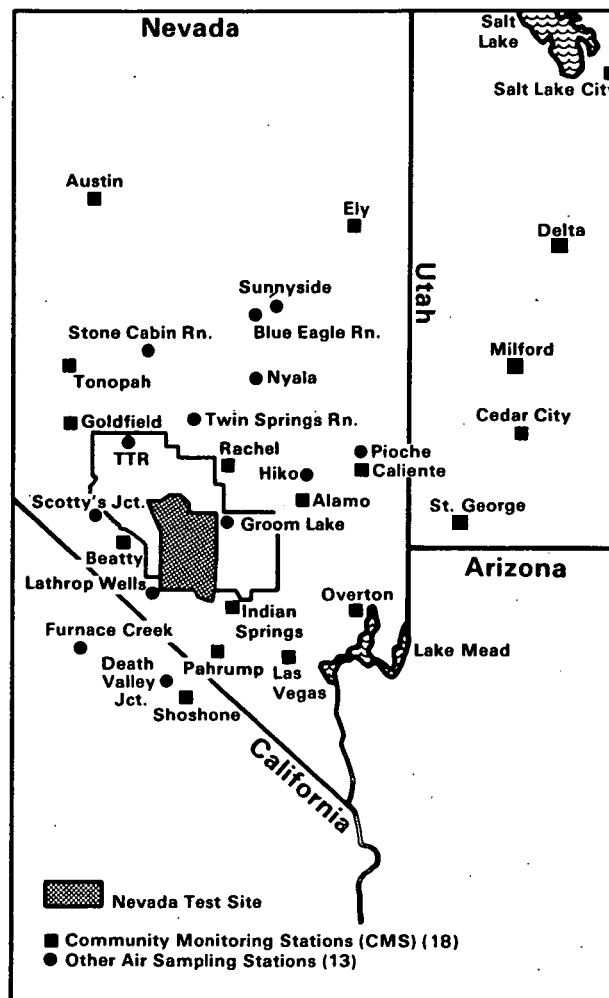
Local citizens have assisted the scientists and technicians at the EPA's Las Vegas Lab for many years. Their participation has augmented the Laboratory's capabilities for monitoring and documenting radiation exposure to people in the offsite areas. These citizens have participated by operating EPA's air samplers at their homes or businesses, by wearing TLDs as they go about their daily affairs, and by providing samples from their dairy cows, gardens, and wells. The involvement of local station managers is in the tradition of this long-standing program.

Over the years the Laboratory has developed methods and equipment that measure very small amounts of radioactivity. The community monitoring stations make use of the most up-to-date equipment commercially available, and the network of citizen-operated stations complements several monitoring networks, such as those for measuring radioactivity in air, water, and milk, that have been in place for many years.



Community Radiation Monitoring Program

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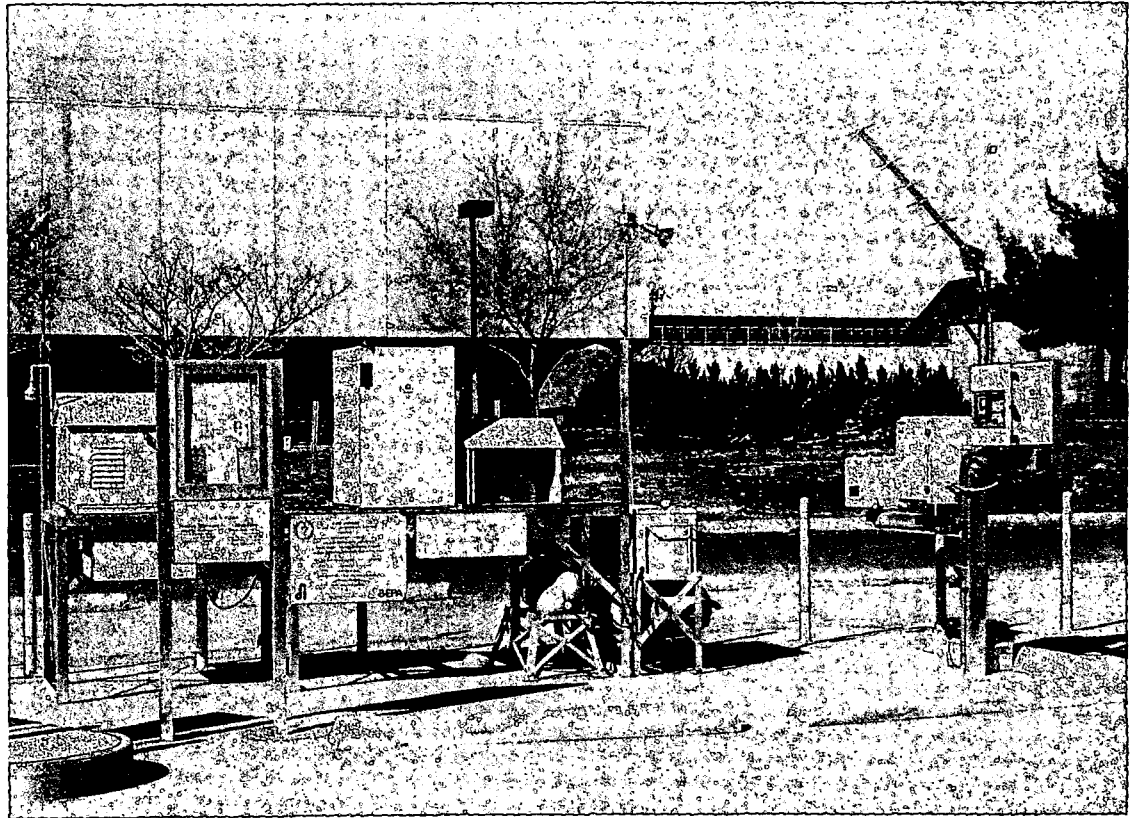
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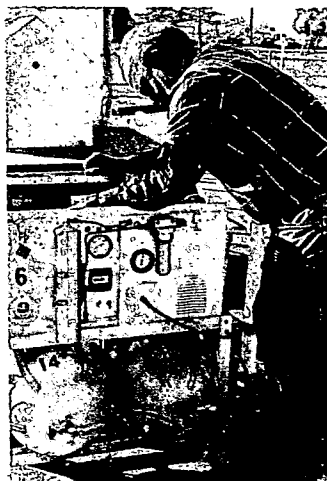
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Figure 5. Data from the Gamma Radiation Exposure Rate Recorder is transmitted through the GOES Satellite System to Las Vegas and the Nevada Test Site



Figure 6. Collecting a sample from a Noble Gas Sampler

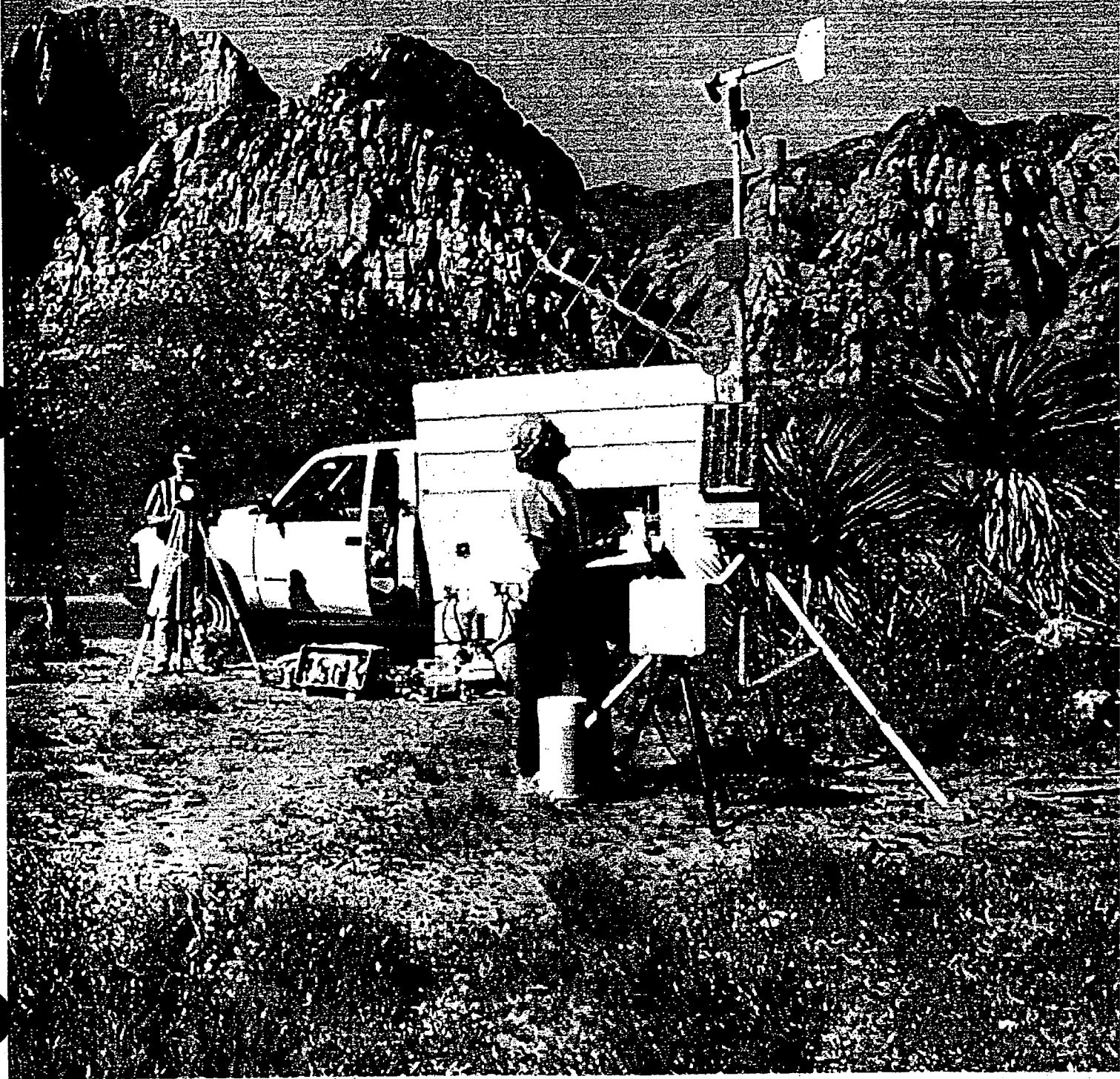


Local citizens have assisted the scientists and technicians at the EPA's Las Vegas Lab for many years. Their participation has augmented the Laboratory's capabilities for monitoring and documenting radiation exposure to people in the offsite areas. These citizens have participated by operating EPA's air samplers at their homes or businesses, by wearing TLDs as they go about their daily affairs, and by providing samples from their dairy cows, gardens, and wells. The involvement of local station managers is in the tradition of this long-standing program.

Over the years the Laboratory has developed methods and equipment that measure very small amounts of radioactivity. The community monitoring stations make use of the most up-to-date equipment commercially available, and the network of citizen-operated stations complements several monitoring networks, such as those for measuring radioactivity in air, water, and milk, that have been in place for many years.



Radiation and Indoor Environments National Laboratory



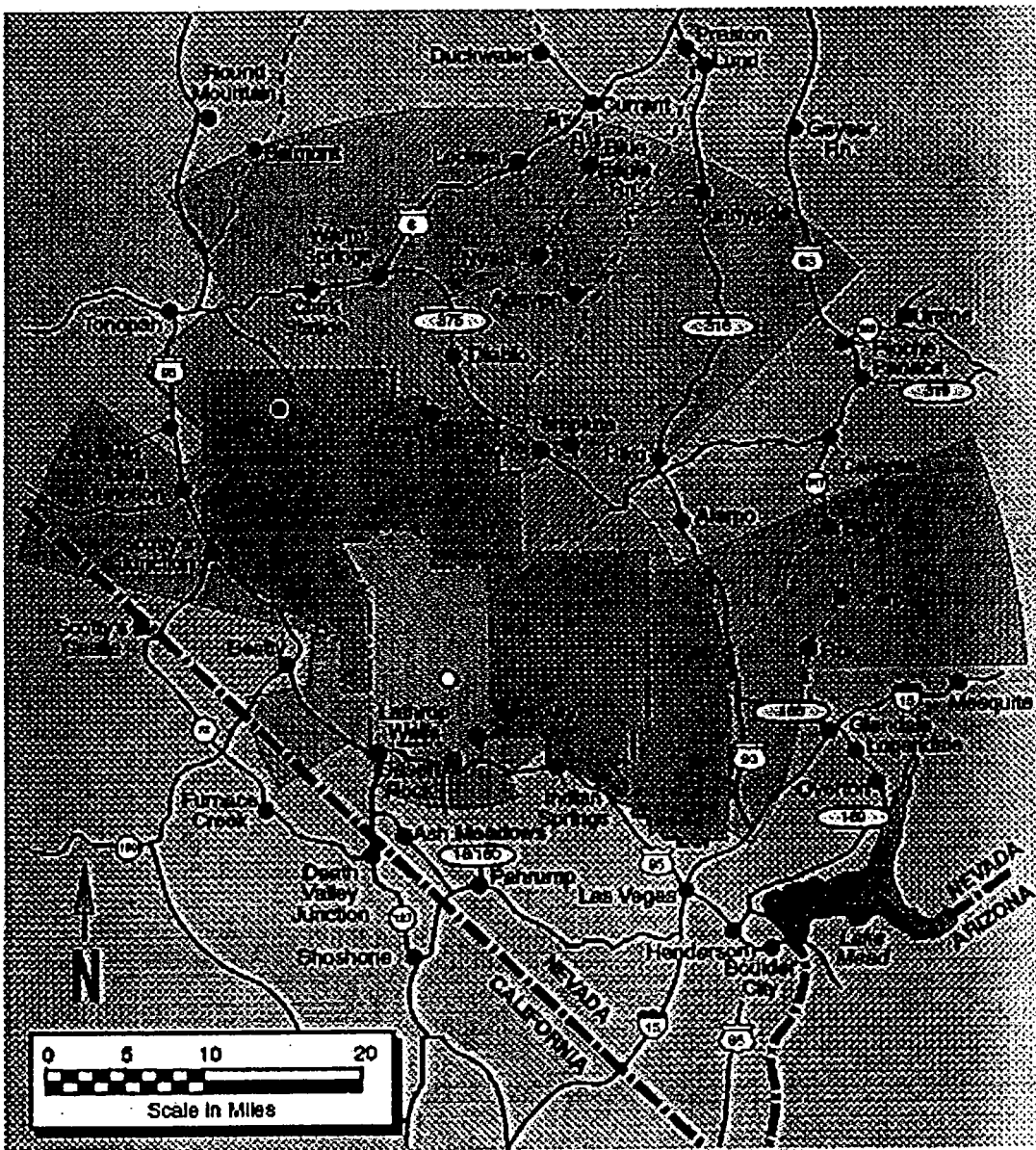


*** OUTLINE ***



- **Setting & Source Term (NTS)**
- **Basic Concepts of Radioactivity**
- **Large-scale Monitoring Results by:**
 - **Sampling & Radiochemical Analysis**
 - **Field Survey Methods**
- **Examples:** Pu Soil Survey (1970s); Radionuclide Inventory & Distribution Program (1980s); Offsite Air Monitoring Program Results (1990s); Emergency Response (Radiological Accident Survey Techniques).

Offsite Area - General



Best Available Copy

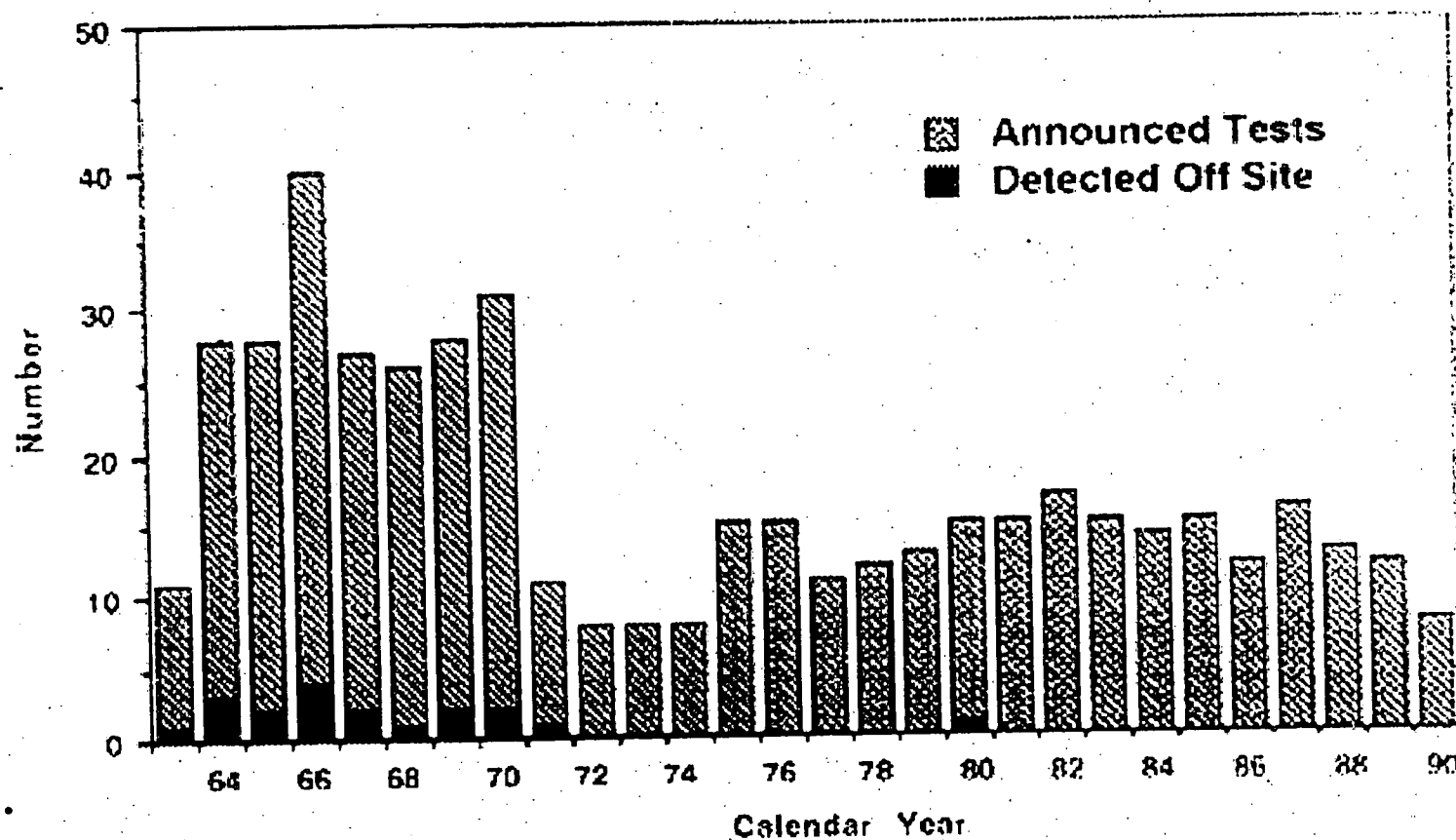
23

TABLE 1. IMPORTANT MANMADE RADIONUCLIDES IN NTS SURFACE SOIL

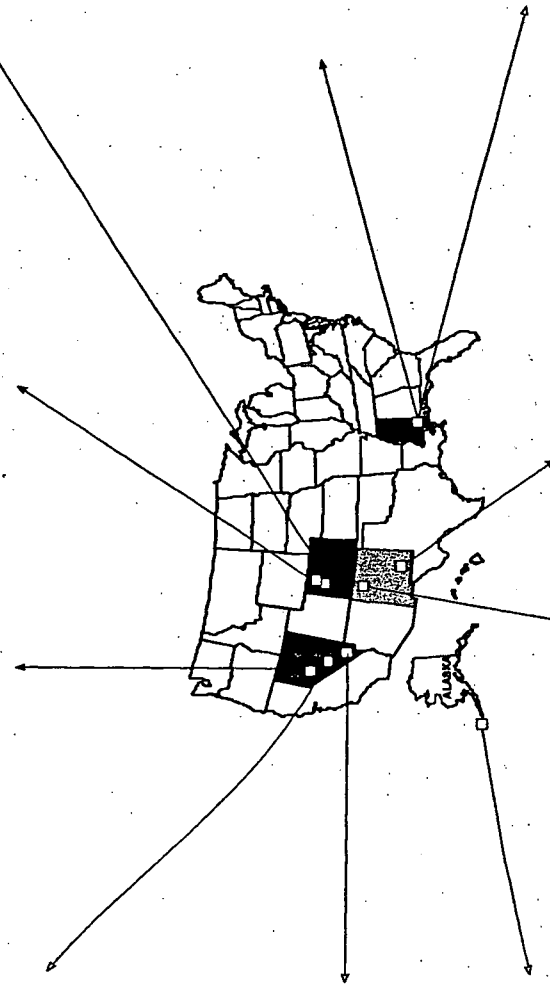
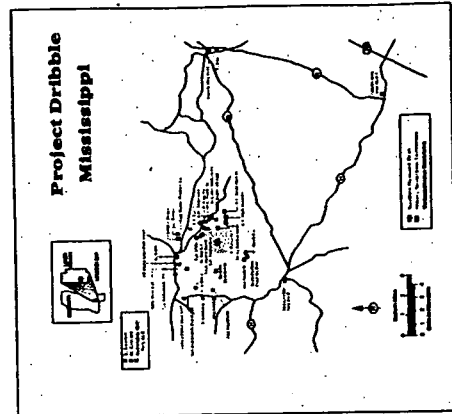
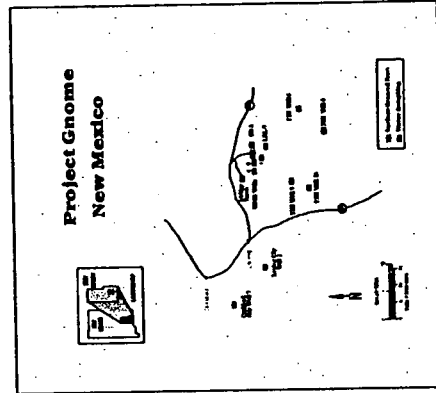
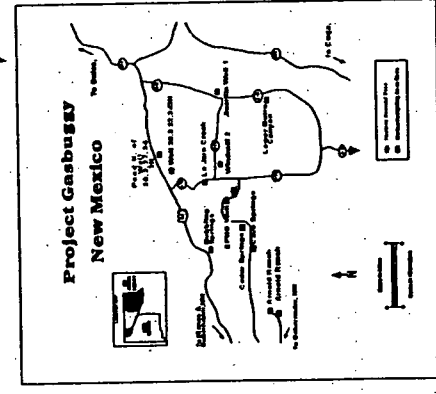
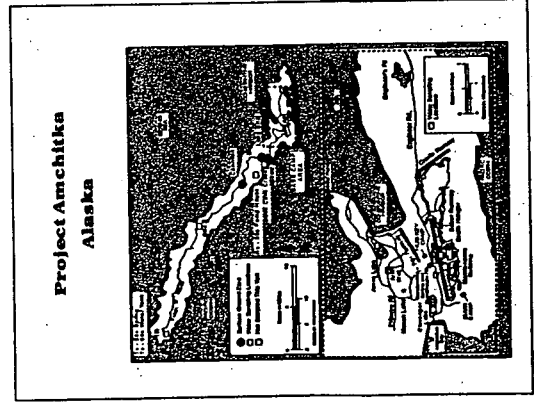
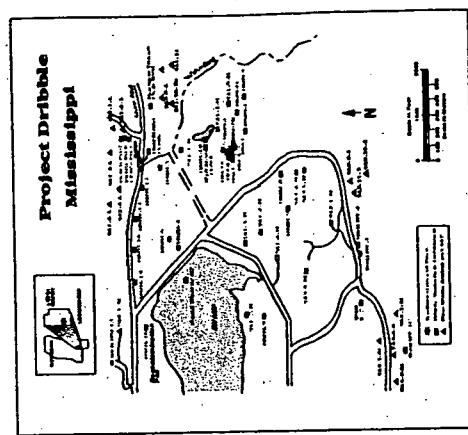
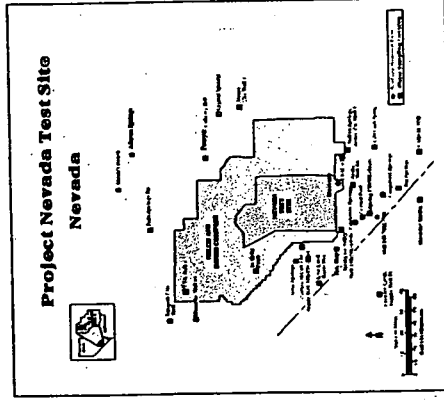
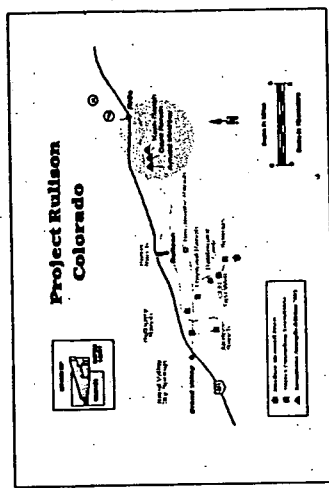
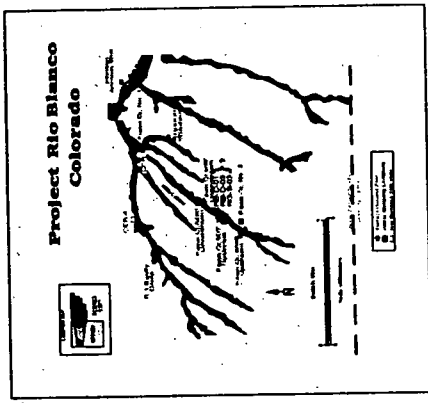
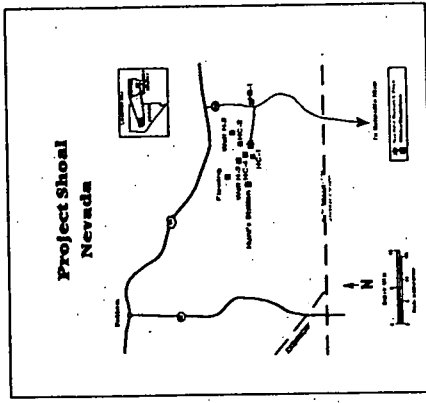
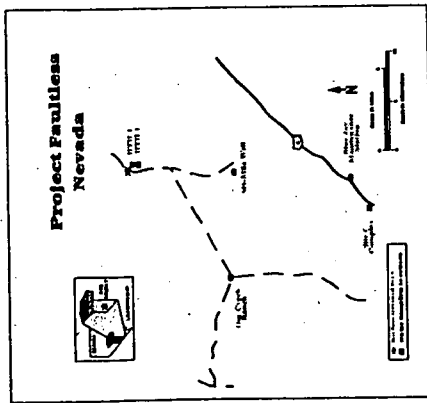
| Radionuclide | Half-life (y) ¹ |
|--------------------|----------------------------|
| ⁶⁰ Co | 5.26 |
| ⁹⁰ Sr | 28.1 |
| ¹⁰¹ Rh | 3.1 |
| ^{102m} Rh | 2.9 |
| ¹²⁵ Sb | 2.7 |
| ¹³³ Ba | 10.7 |
| ¹³⁴ Cs | 2.05 |
| ¹³⁷ Cs | 30.2 |
| ¹⁵² Eu | 13. |
| ¹⁵⁴ Eu | 16. |
| ¹⁵⁵ Eu | 1.81 |
| ¹⁷⁴ Lu | 3.6 |
| ²³⁸ Pu | 86. |
| ²³⁹ Pu | 24,400. |
| ²⁴⁰ Pu | 6,580. |
| ²⁴¹ Am | 458. |

¹Most values are from the *CRC Handbook of Chemistry and Physics*, 65th Edition (1984), CRC Press, Boca Raton, Florida; the value for ¹³³Ba is from the *Table of Isotopes*, 7th Edition (1978), Wiley, New York.

Underground Tests Designed for Containment



Underground tests since August 5, 1963 that
 accidentally released radioactivity detectable off site.

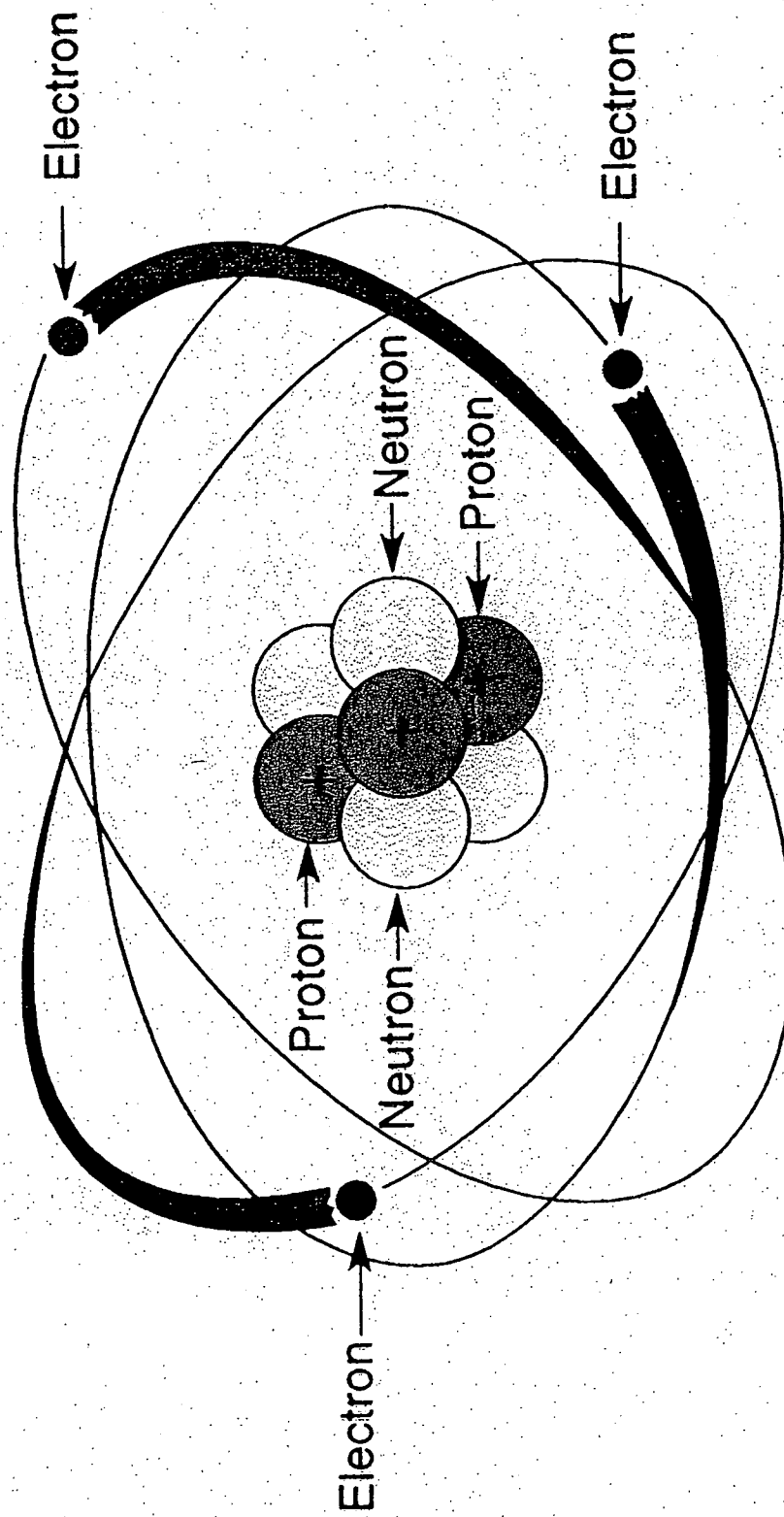


Periodic Table of the Elements

| | | | | | | | | | | | | | | | | | | | | | | | | | |
|---------|--|--|--|--|--|--|--|--|--|--|--|--------|--|--------|--|--------|--|------------|--|---------------|--|----------------|--|-------------|--|
| | | | | | | | | | | | | | | | | | | NON-METALS | | OXYGEN FAMILY | | HALOGEN FAMILY | | INERT GASES | |
| IA | | | | | | | | | | | | METALS | | IIIA | | IVA | | VA | | VIA | | VIIA | | | |
| 1.0080 | | | | | | | | | | | | 5 | | 6 | | 7 | | 8 | | 9 | | 10 | | 20.18 | |
| H | | | | | | | | | | | | B | | C | | N | | O | | F | | Ne | | 4.003 | |
| 1 | | | | | | | | | | | | 10.81 | | 12.011 | | 14.007 | | 15.999 | | 18.998 | | 20.18 | | | |
| IIA | | | | | | | | | | | | 11 | | 12 | | 13 | | 14 | | 15 | | 16 | | 17 | |
| Li | | | | | | | | | | | | Al | | Si | | P | | S | | Cl | | Ar | | 36.96 | |
| 3 | | | | | | | | | | | | 26.987 | | 28.086 | | 30.974 | | 32.064 | | 35.453 | | 39.948 | | 39.948 | |
| Be | | | | | | | | | | | | 13 | | 14 | | 15 | | 16 | | 17 | | 18 | | 40.08 | |
| 4 | | | | | | | | | | | | Ga | | Ge | | As | | Se | | Br | | Kr | | 83.60 | |
| 22.990 | | | | | | | | | | | | 69.72 | | 72.59 | | 74.921 | | 78.96 | | 79.909 | | 83.60 | | 83.60 | |
| Na | | | | | | | | | | | | 31 | | 32 | | 33 | | 34 | | 35 | | 36 | | 83.60 | |
| 11 | | | | | | | | | | | | 13 | | 14 | | 15 | | 16 | | 17 | | 18 | | 40.08 | |
| Mg | | | | | | | | | | | | Al | | Si | | P | | S | | Cl | | Ar | | 36.96 | |
| 12 | | | | | | | | | | | | 26.987 | | 28.086 | | 30.974 | | 32.064 | | 35.453 | | 39.948 | | 39.948 | |
| 39.102 | | | | | | | | | | | | 69.72 | | 72.59 | | 74.921 | | 78.96 | | 79.909 | | 83.60 | | 83.60 | |
| K | | | | | | | | | | | | 31 | | 32 | | 33 | | 34 | | 35 | | 36 | | 83.60 | |
| 19 | | | | | | | | | | | | Ga | | Ge | | As | | Se | | Br | | Kr | | 83.60 | |
| 85.47 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 131.30 | |
| Rb | | | | | | | | | | | | In | | Sn | | Sb | | Te | | I | | Xe | | 131.30 | |
| 37 | | | | | | | | | | | | 49 | | 50 | | 51 | | 52 | | 53 | | 54 | | 131.30 | |
| 87.62 | | | | | | | | | | | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 131.30 | | 131.30 | |
| Sr | | | | | | | | | | | | 50 | | 51 | | 52 | | 53 | | 54 | | 55 | | 132.905 | |
| 38 | | | | | | | | | | | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 131.30 | | 132.905 | |
| 88.906 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Y | | | | | | | | | | | | In | | Sn | | Sb | | Te | | I | | Xe | | 131.30 | |
| 39 | | | | | | | | | | | | 49 | | 50 | | 51 | | 52 | | 53 | | 54 | | 131.30 | |
| 88.906 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Zr | | | | | | | | | | | | 50 | | 51 | | 52 | | 53 | | 54 | | 55 | | 132.905 | |
| 40 | | | | | | | | | | | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 131.30 | | 132.905 | |
| 91.22 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Nb | | | | | | | | | | | | In | | Sn | | Sb | | Te | | I | | Xe | | 131.30 | |
| 41 | | | | | | | | | | | | 49 | | 50 | | 51 | | 52 | | 53 | | 54 | | 131.30 | |
| 92.906 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Mo | | | | | | | | | | | | 50 | | 51 | | 52 | | 53 | | 54 | | 55 | | 132.905 | |
| 42 | | | | | | | | | | | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 131.30 | | 132.905 | |
| 93.94 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Tc | | | | | | | | | | | | In | | Sn | | Sb | | Te | | I | | Xe | | 131.30 | |
| 43 | | | | | | | | | | | | 49 | | 50 | | 51 | | 52 | | 53 | | 54 | | 131.30 | |
| 101.07 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Ru | | | | | | | | | | | | 50 | | 51 | | 52 | | 53 | | 54 | | 55 | | 132.905 | |
| 44 | | | | | | | | | | | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 131.30 | | 132.905 | |
| 102.805 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Rh | | | | | | | | | | | | In | | Sn | | Sb | | Te | | I | | Xe | | 131.30 | |
| 45 | | | | | | | | | | | | 49 | | 50 | | 51 | | 52 | | 53 | | 54 | | 131.30 | |
| 106.4 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Pd | | | | | | | | | | | | 50 | | 51 | | 52 | | 53 | | 54 | | 55 | | 132.905 | |
| 46 | | | | | | | | | | | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 131.30 | | 132.905 | |
| 107.870 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Ag | | | | | | | | | | | | In | | Sn | | Sb | | Te | | I | | Xe | | 131.30 | |
| 47 | | | | | | | | | | | | 49 | | 50 | | 51 | | 52 | | 53 | | 54 | | 131.30 | |
| 108.6 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Ni | | | | | | | | | | | | 50 | | 51 | | 52 | | 53 | | 54 | | 55 | | 132.905 | |
| 28 | | | | | | | | | | | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 131.30 | | 132.905 | |
| 58.71 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Cu | | | | | | | | | | | | In | | Sn | | Sb | | Te | | I | | Xe | | 131.30 | |
| 29 | | | | | | | | | | | | 49 | | 50 | | 51 | | 52 | | 53 | | 54 | | 131.30 | |
| 63.54 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Zn | | | | | | | | | | | | 50 | | 51 | | 52 | | 53 | | 54 | | 55 | | 132.905 | |
| 30 | | | | | | | | | | | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 131.30 | | 132.905 | |
| 65.37 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Ga | | | | | | | | | | | | In | | Sn | | Sb | | Te | | I | | Xe | | 131.30 | |
| 31 | | | | | | | | | | | | 49 | | 50 | | 51 | | 52 | | 53 | | 54 | | 131.30 | |
| 69.72 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Fe | | | | | | | | | | | | 50 | | 51 | | 52 | | 53 | | 54 | | 55 | | 132.905 | |
| 26 | | | | | | | | | | | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 131.30 | | 132.905 | |
| 55.847 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Co | | | | | | | | | | | | In | | Sn | | Sb | | Te | | I | | Xe | | 131.30 | |
| 27 | | | | | | | | | | | | 49 | | 50 | | 51 | | 52 | | 53 | | 54 | | 131.30 | |
| 58.933 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Ni | | | | | | | | | | | | 50 | | 51 | | 52 | | 53 | | 54 | | 55 | | 132.905 | |
| 28 | | | | | | | | | | | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 131.30 | | 132.905 | |
| 58.71 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Cu | | | | | | | | | | | | In | | Sn | | Sb | | Te | | I | | Xe | | 131.30 | |
| 29 | | | | | | | | | | | | 49 | | 50 | | 51 | | 52 | | 53 | | 54 | | 131.30 | |
| 63.54 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Zn | | | | | | | | | | | | 50 | | 51 | | 52 | | 53 | | 54 | | 55 | | 132.905 | |
| 30 | | | | | | | | | | | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 131.30 | | 132.905 | |
| 65.37 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Ga | | | | | | | | | | | | In | | Sn | | Sb | | Te | | I | | Xe | | 131.30 | |
| 31 | | | | | | | | | | | | 49 | | 50 | | 51 | | 52 | | 53 | | 54 | | 131.30 | |
| 69.72 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Ge | | | | | | | | | | | | 50 | | 51 | | 52 | | 53 | | 54 | | 55 | | 132.905 | |
| 32 | | | | | | | | | | | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 131.30 | | 132.905 | |
| 72.59 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| As | | | | | | | | | | | | In | | Sn | | Sb | | Te | | I | | Xe | | 131.30 | |
| 33 | | | | | | | | | | | | 49 | | 50 | | 51 | | 52 | | 53 | | 54 | | 131.30 | |
| 74.921 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Se | | | | | | | | | | | | 50 | | 51 | | 52 | | 53 | | 54 | | 55 | | 132.905 | |
| 34 | | | | | | | | | | | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 131.30 | | 132.905 | |
| 78.96 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Br | | | | | | | | | | | | In | | Sn | | Sb | | Te | | I | | Xe | | 131.30 | |
| 35 | | | | | | | | | | | | 49 | | 50 | | 51 | | 52 | | 53 | | 54 | | 131.30 | |
| 79.909 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Kr | | | | | | | | | | | | 50 | | 51 | | 52 | | 53 | | 54 | | 55 | | 132.905 | |
| 36 | | | | | | | | | | | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 131.30 | | 132.905 | |
| 83.60 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Rb | | | | | | | | | | | | In | | Sn | | Sb | | Te | | I | | Xe | | 131.30 | |
| 37 | | | | | | | | | | | | 49 | | 50 | | 51 | | 52 | | 53 | | 54 | | 131.30 | |
| 85.47 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Sr | | | | | | | | | | | | 50 | | 51 | | 52 | | 53 | | 54 | | 55 | | 132.905 | |
| 38 | | | | | | | | | | | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 131.30 | | 132.905 | |
| 87.62 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Y | | | | | | | | | | | | In | | Sn | | Sb | | Te | | I | | Xe | | 131.30 | |
| 39 | | | | | | | | | | | | 49 | | 50 | | 51 | | 52 | | 53 | | 54 | | 131.30 | |
| 88.906 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Zr | | | | | | | | | | | | 50 | | 51 | | 52 | | 53 | | 54 | | 55 | | 132.905 | |
| 40 | | | | | | | | | | | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 131.30 | | 132.905 | |
| 91.22 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Nb | | | | | | | | | | | | In | | Sn | | Sb | | Te | | I | | Xe | | 131.30 | |
| 41 | | | | | | | | | | | | 49 | | 50 | | 51 | | 52 | | 53 | | 54 | | 131.30 | |
| 92.906 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Mo | | | | | | | | | | | | 50 | | 51 | | 52 | | 53 | | 54 | | 55 | | 132.905 | |
| 42 | | | | | | | | | | | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 131.30 | | 132.905 | |
| 93.94 | | | | | | | | | | | | 114.02 | | 118.69 | | 121.75 | | 127.60 | | 126.90 | | 131.30 | | 132.905 | |
| Tc | | | | | | | | | | | | In | | Sn | | Sb | | Te | | I | | Xe | | 131.30 | |

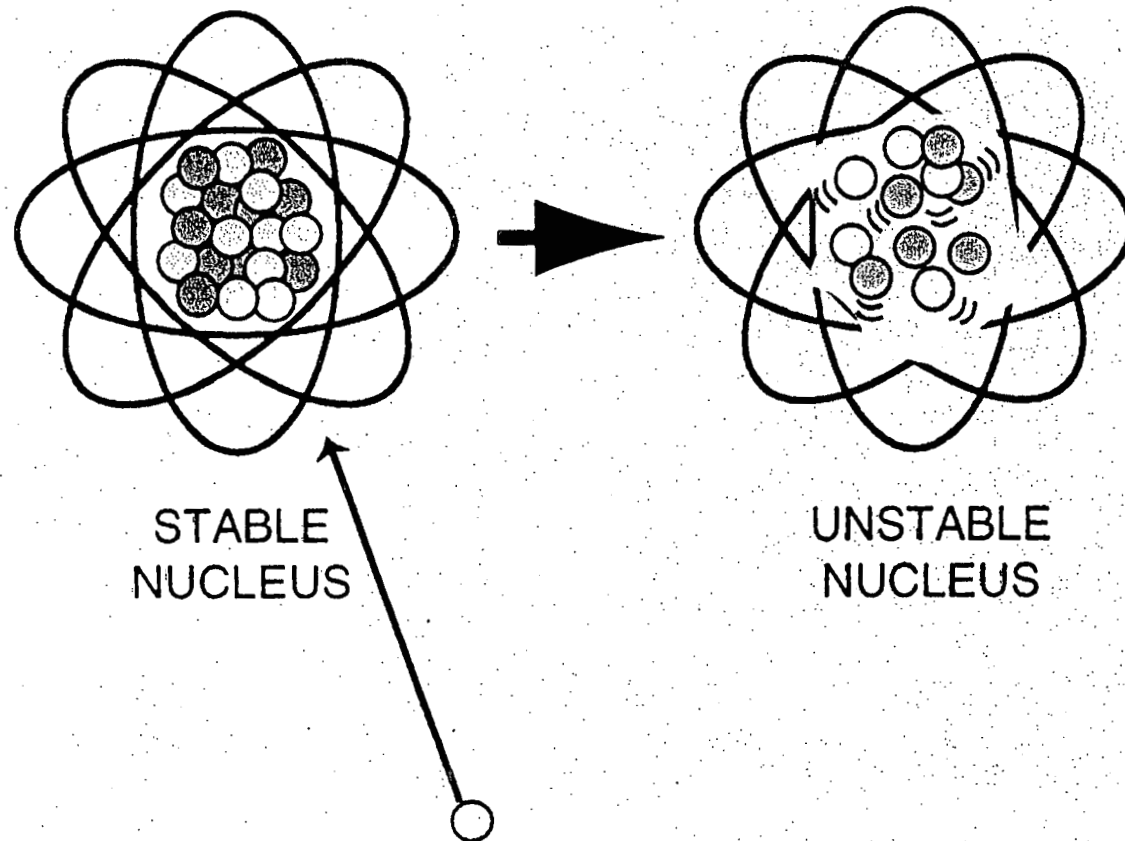
27

ATOMS ARE THE BUILDING BLOCKS OF ALL MATTER



Lithium atom used as example

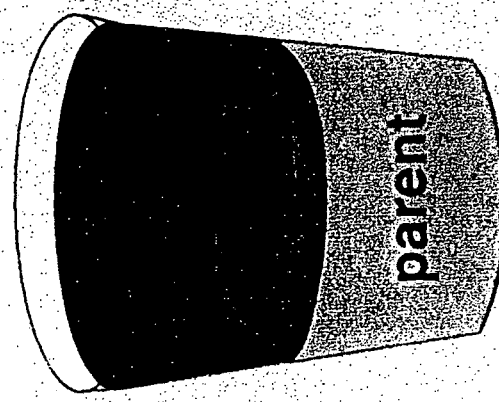
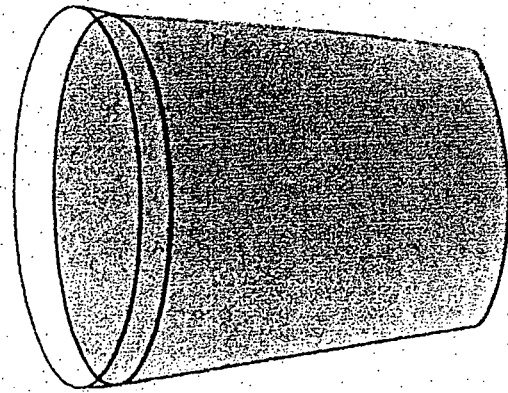
NUCLEI MAY BE STABLE OR UNSTABLE



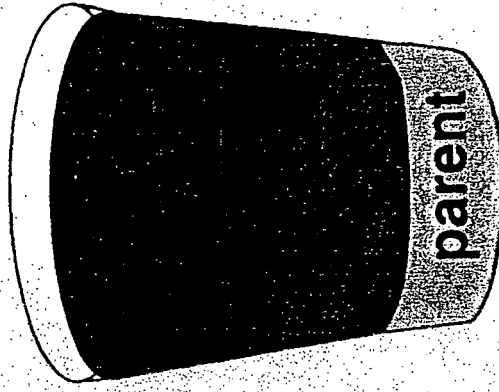
Do any or all of the following:

- **Emit particle**
 α
 β
Neutron
- **Emit EM radiation**
 γ
- **Split (fission)**

HALF-LIFE

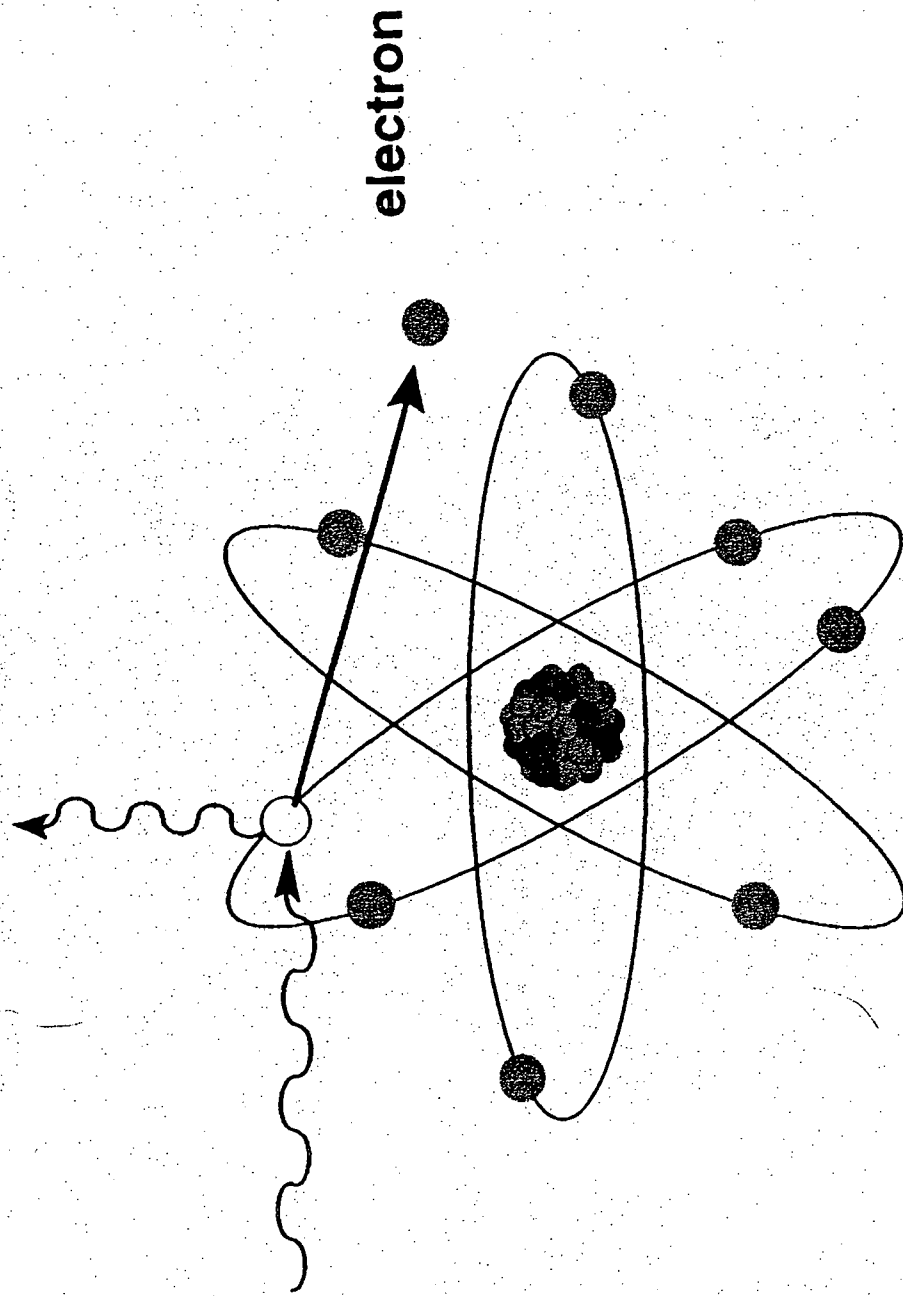


One half-life



Two half-lives

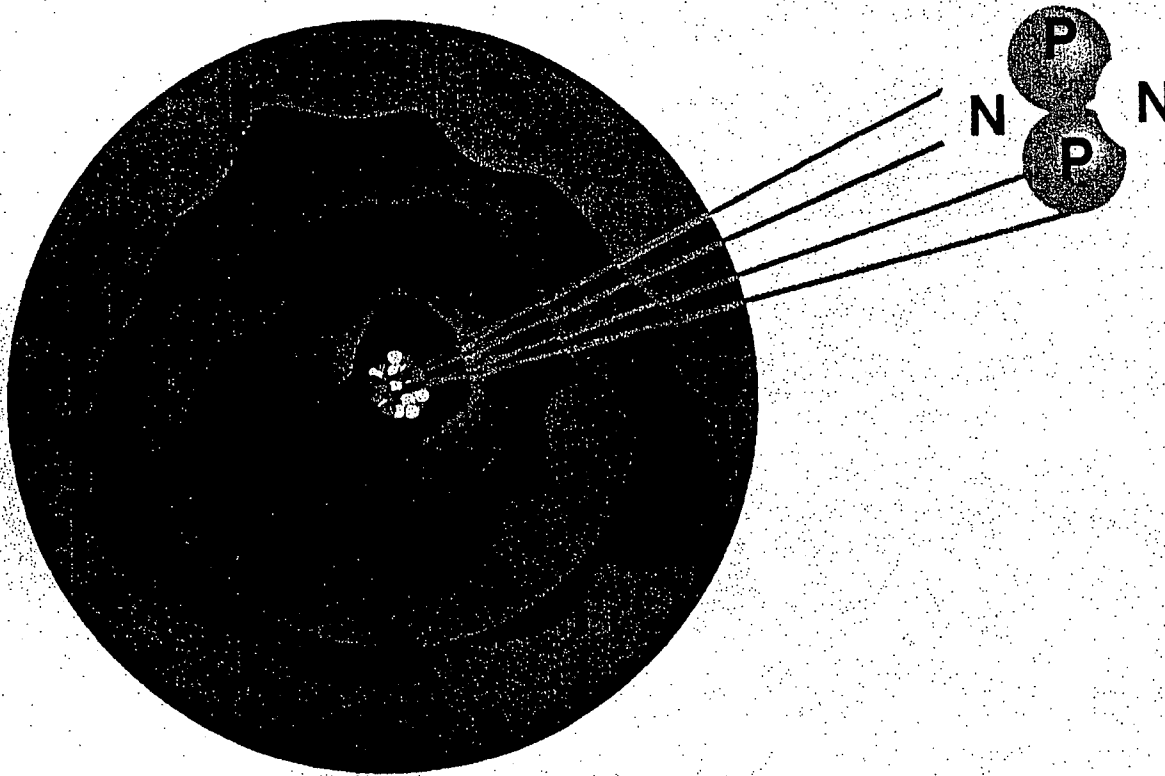
IONIZING RADIATION has enough energy to
remove electrons from atoms.



ALPHA PARTICLE

Mass = 4

Charge = +2



Typical Penetration

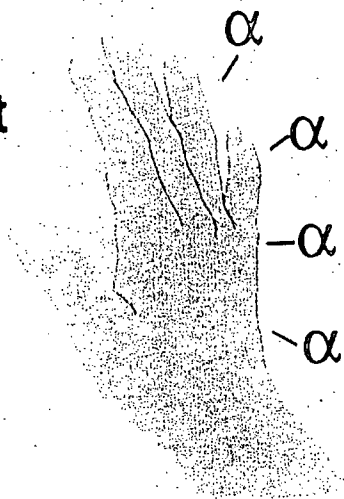
Inches of air

Typical Stop

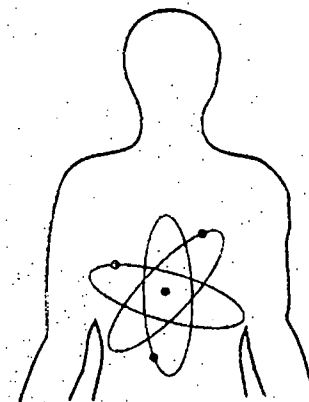
Plastic wrap
Epidermis
Paper

ALPHA RADIATION is stopped by your skin;
it is only a hazard when inside your body.

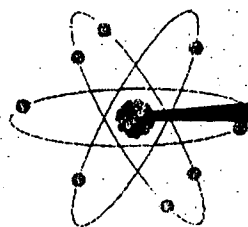
cannot get
through
skin



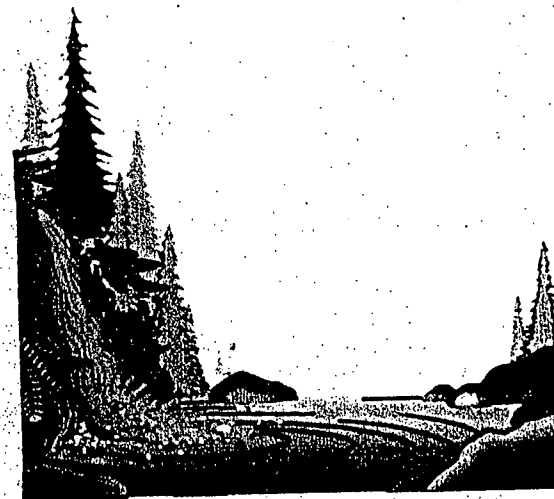
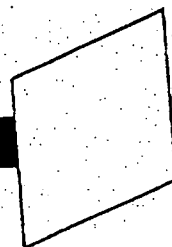
internal
hazard



alpha



Stopped by Paper



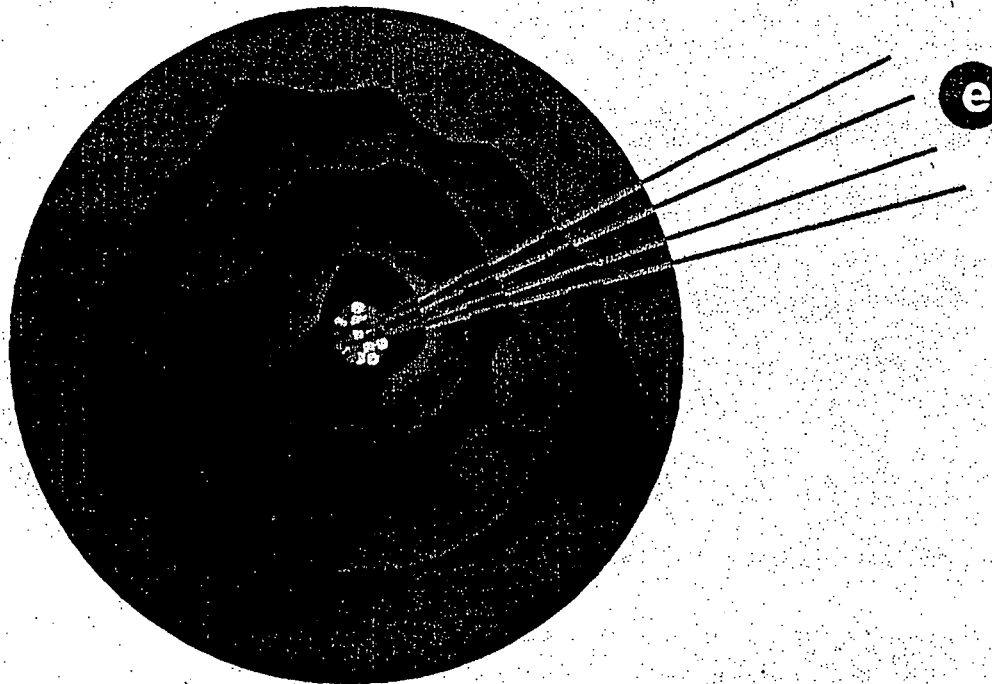
soil, radon, and heavy
man-made elements

33

BETA PARTICLE

Mass = 0.00053

Charge = -1



Typical Penetration

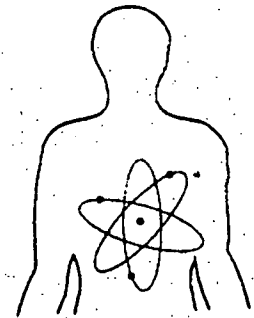
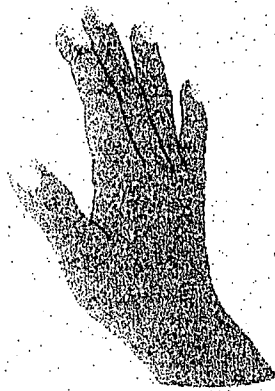
Feet of air
Inches of plastic
Inches of paper

Typical Stop

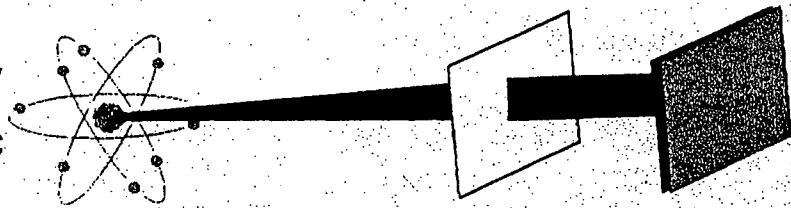
Metal foil

BETA RADIATION can penetrate the skin;
therefore, it can be a skin or eye hazard.

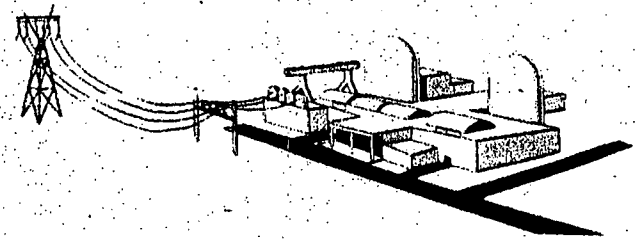
skin, eye, and
internal hazard



stopped by
thin plastic



medical, research,
reactors, fallout



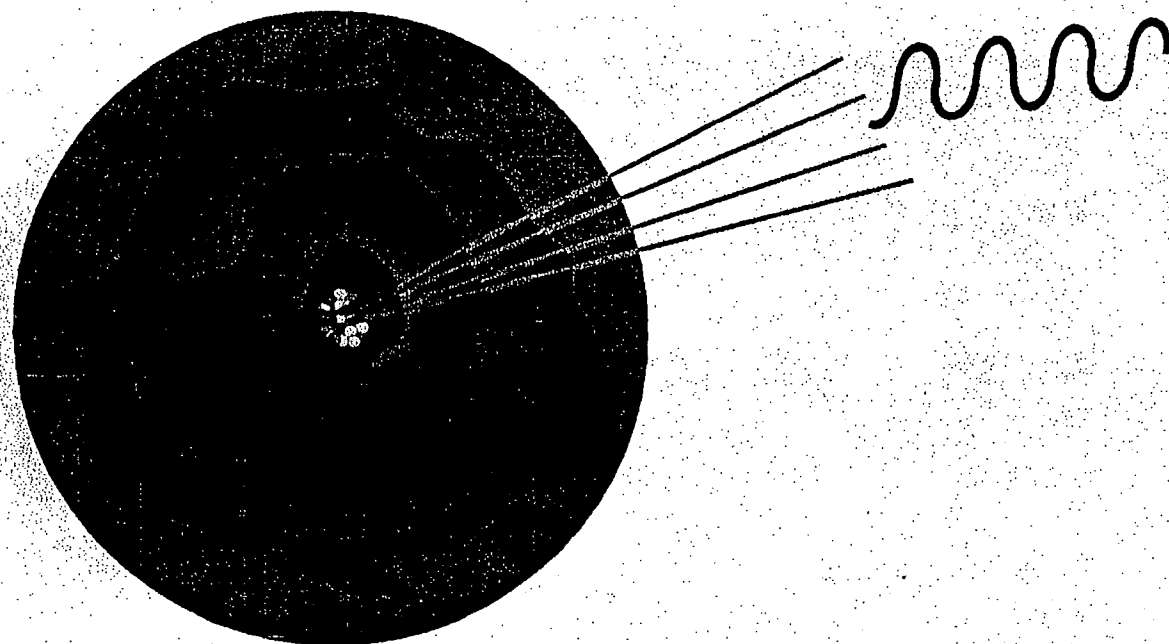
natural food,
water, air

35

GAMMA RAY

Mass = 0

Charge = None



Typical Penetration
(strong energy dependence)

Feet of concrete
Feet of water
Many inches of metal
Miles of air

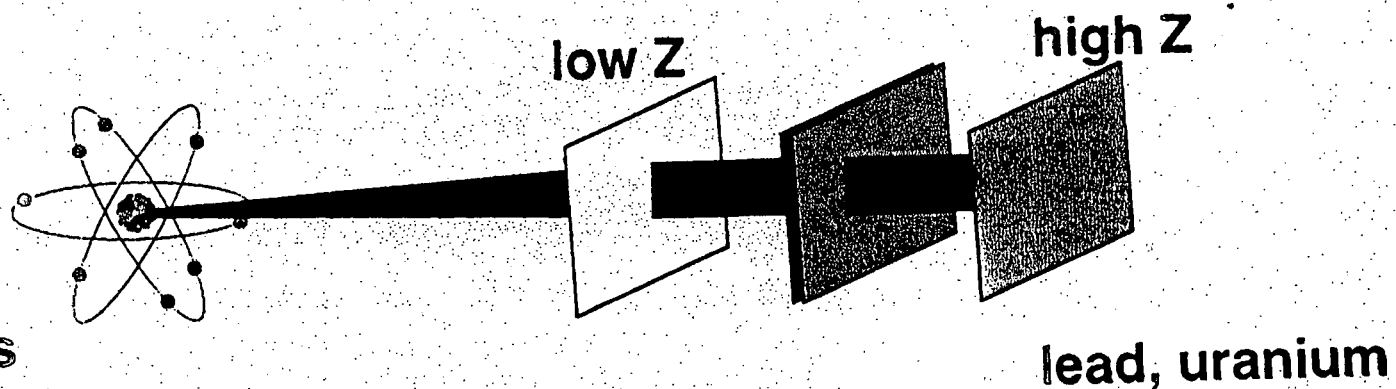
Typical Stop

Feet of water
Feet of metals

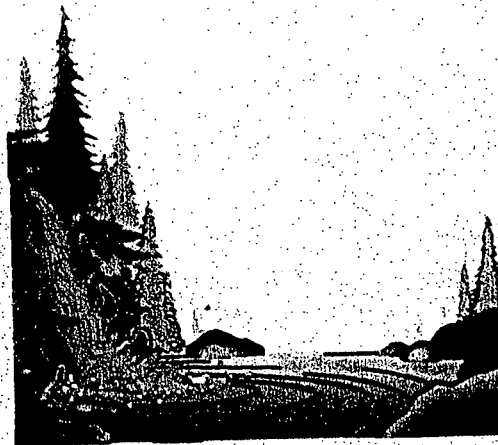
26

**X and GAMMA RADIATION can penetrate into
your body delivering a deep dose.**

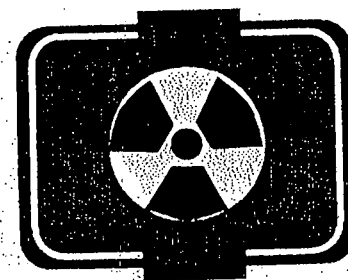
**stopped by
dense shielding
or large amounts
of ordinary materials**



**naturally present
in soil and in
cosmic radiation**

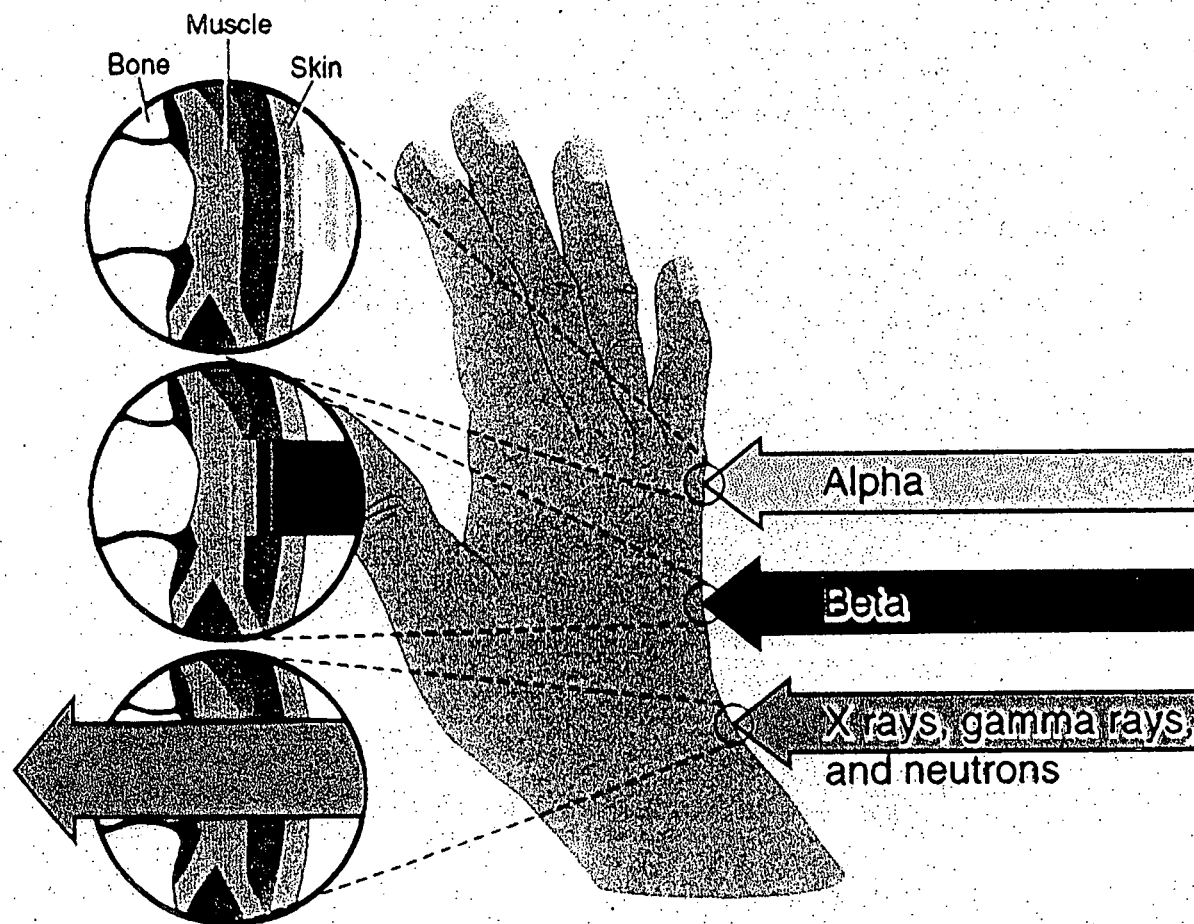


**medical,
industrial,
radioactive
sources**



37

TYPES OF RADIATION RELEASED BY RADIOACTIVE ISOTOPES



The shielding required to "stop" the radiation depends on the kind of radiation and its energy.



ALPHA SPECTROSCOPY



- **Advantages:**

- Good Accuracy & Precision
- Low Background (Pu & Am)
- Excellent Detection Limits

- **Disadvantages (Sources of Uncertainty):**

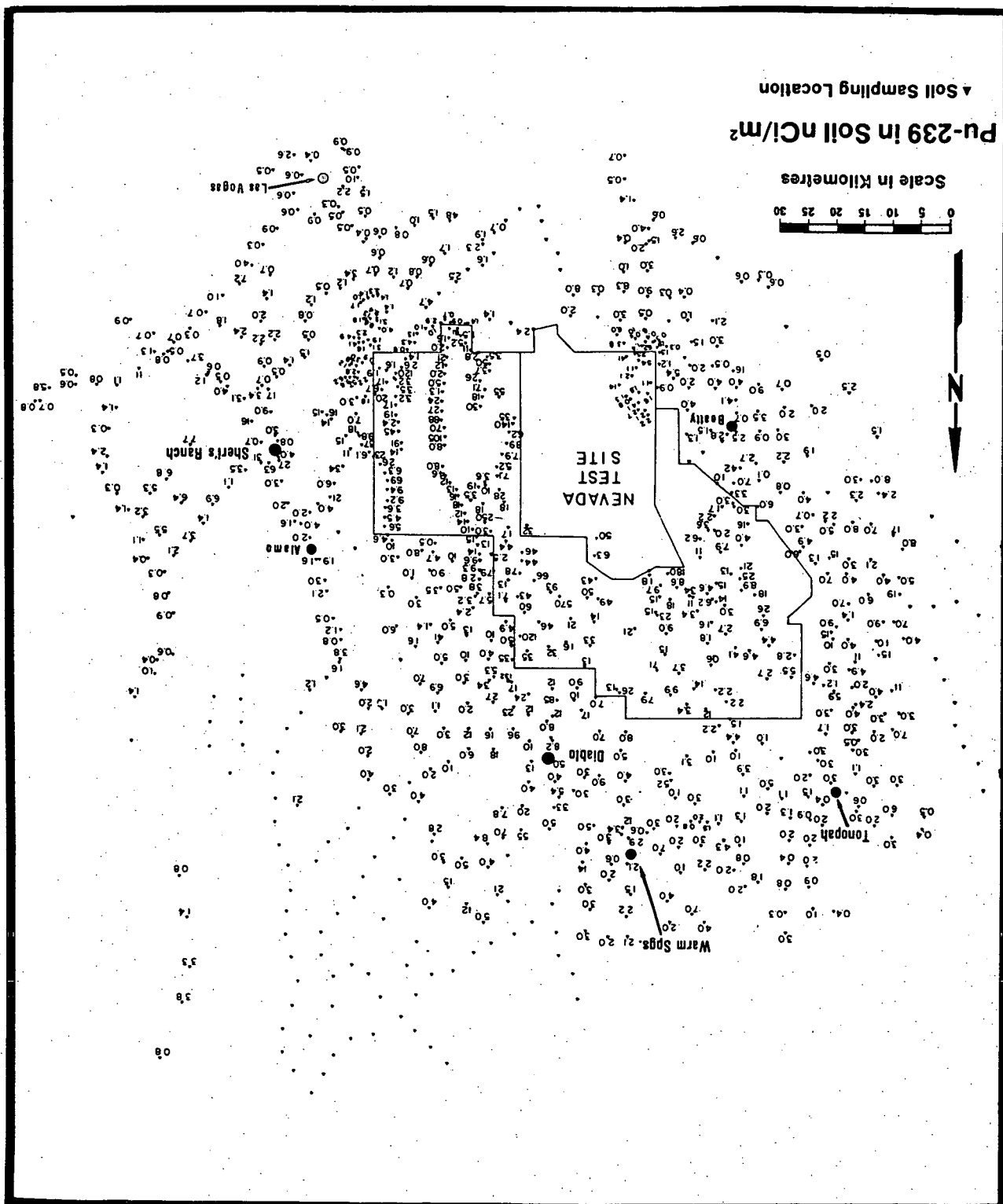
- Labor Intensive, High-skill
- Inherent sampling uncertainty (Soil) or collection efficiency (Air)
- Large number of samples (cost)

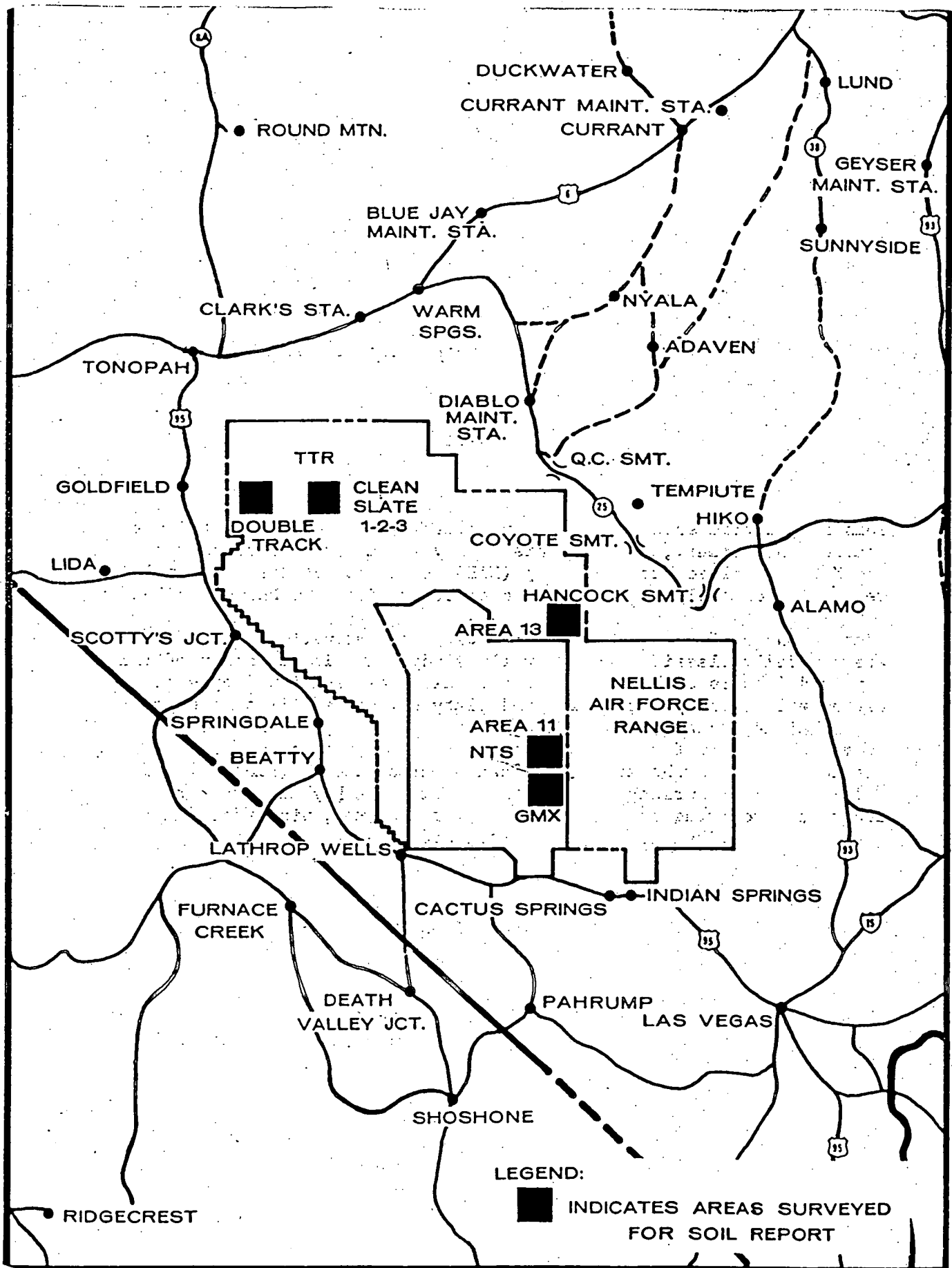
31

Best Available Copy

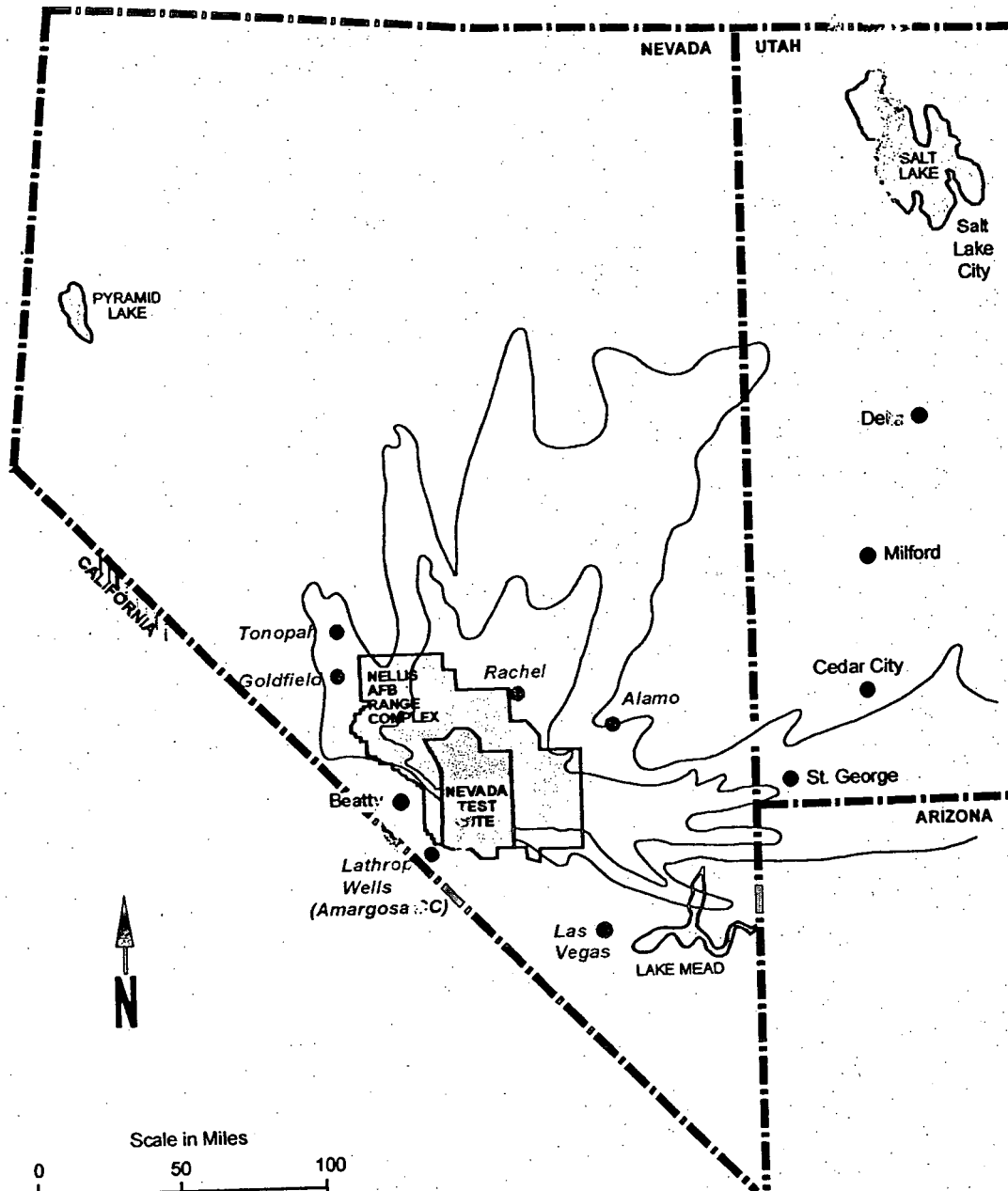
190

Figure 2. Plutonium-239 in Soil

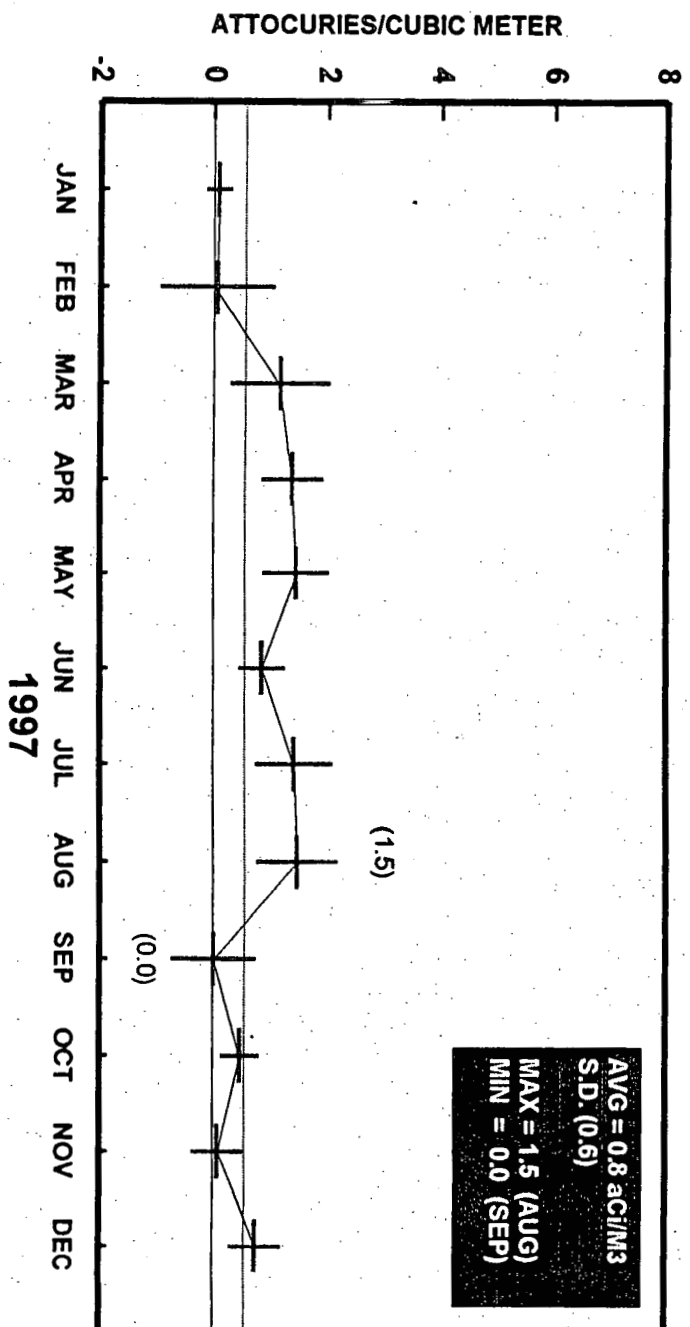
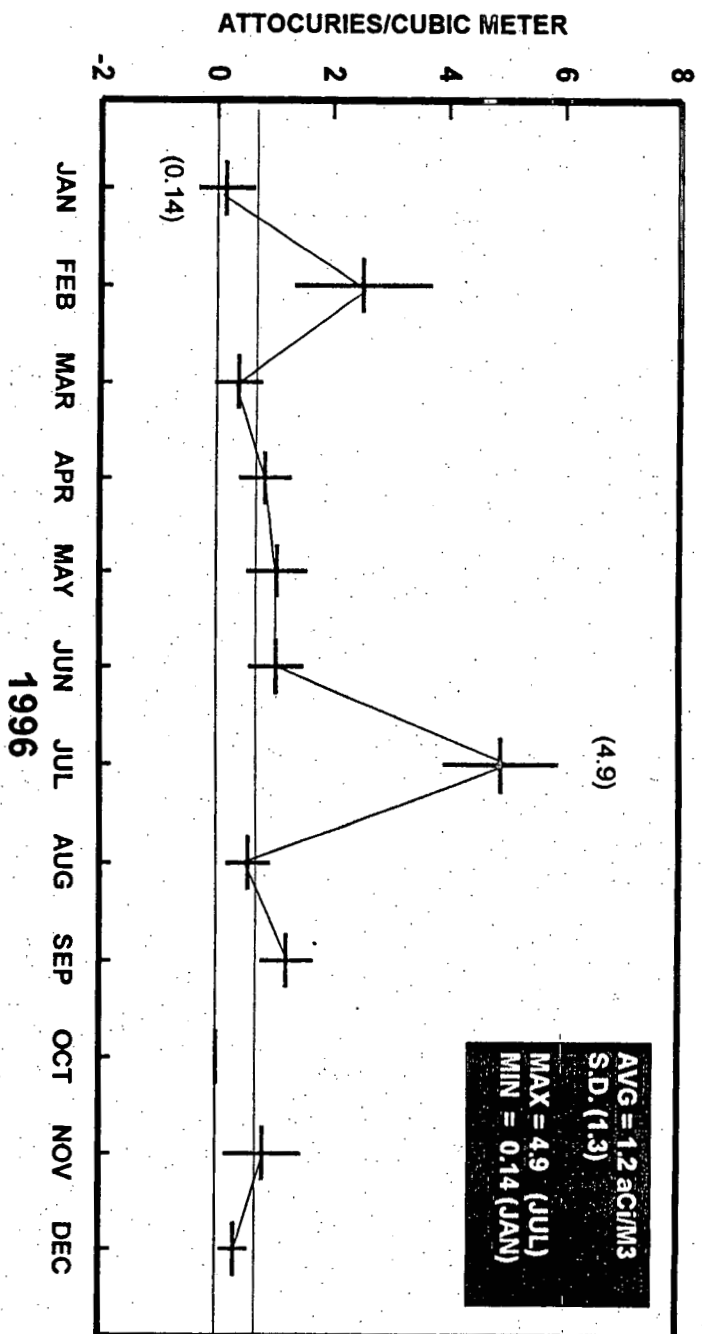




EPA Hi-Volume Air Sampling Sites

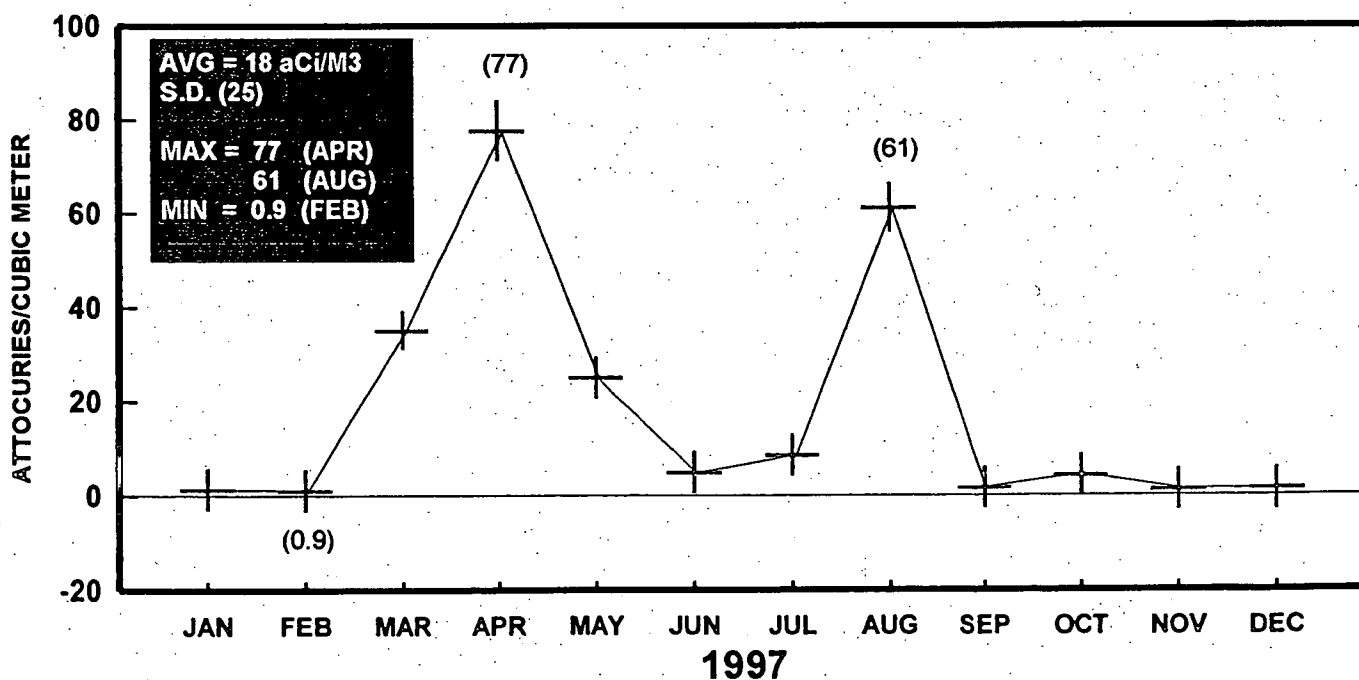
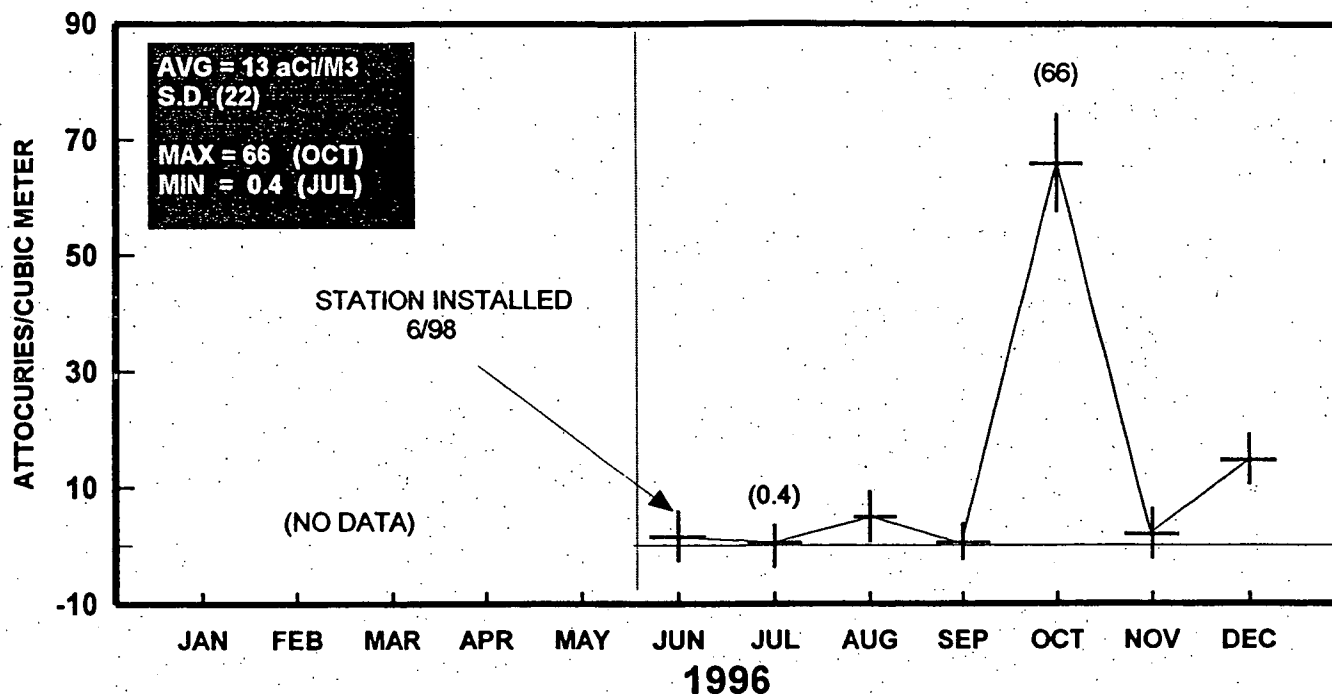


PLUTONIUM IN AIR - ALAMO, NV



42

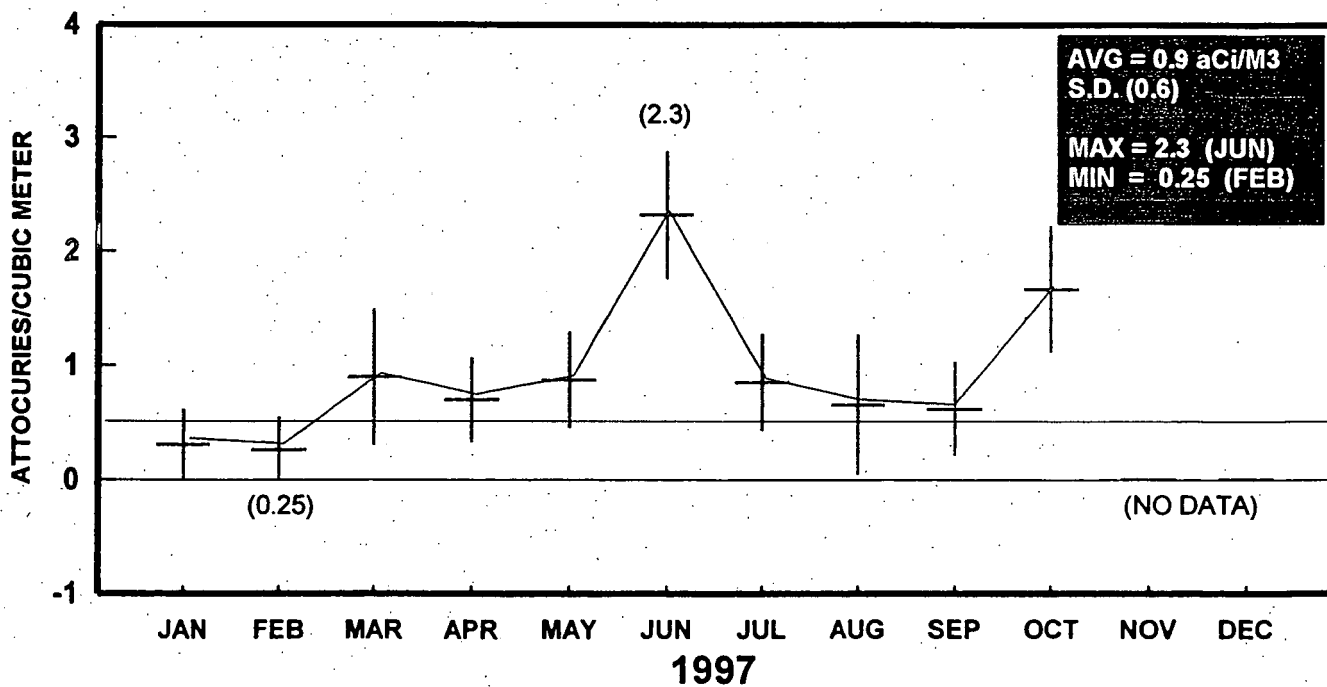
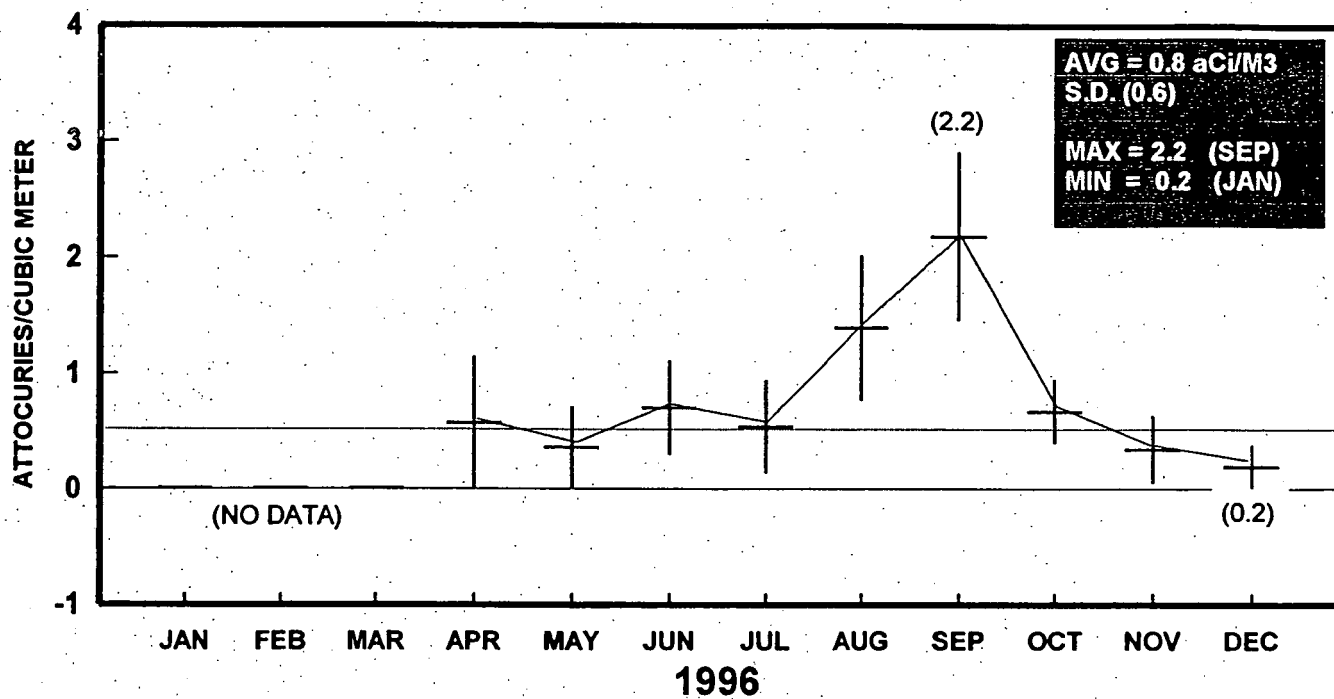
PLUTONIUM IN AIR - RACHEL, NV



43

HIGHEST ACT

PLUTONIUM IN AIR - TONOPAH, NV



Summary of 1996 - 1997 Plutonium in Air Data

ATTOCURIES/CUBIC METER

| 1996 | AVG. | S.D. | MIN. | MON. | MAX. | MON. |
|--------------|------|------|------|------|------|------|
| 1. Alamo | 1.2 | 1.3 | 0.14 | JAN | 4.9 | JUL |
| 2. Amargosa | 0.7 | 0.5 | 0.2 | SEP | 1.6 | AUG |
| 3. Goldfield | 1.3 | 0.9 | 0.06 | MAR | 2.8 | SEP |
| 4. Las Vegas | 0.7 | 0.7 | 0.0 | FEB | 2.2 | SEP |
| 5. Rachel | 13 | 22 | 0.4 | JUL | 66 | OCT |
| 6. Tonopah | 0.8 | 0.6 | 0.2 | JAN | 2.2 | SEP |

ATTOCURIES/CUBIC METER

| 1997 | AVG. | S.D. | MIN. | MON. | MAX. | MON. |
|--------------|------|------|------|------|----------|------------|
| 1. Alamo | 0.8 | 0.6 | 0.0 | SEP | 1.5 | AUG |
| 2. Amargosa | 1.5 | 2.3 | 0.2 | NOV | 8.0 | MAY |
| 3. Goldfield | 0.7 | 0.7 | 0.17 | OCT | 3.3 | SEP |
| 4. Las Vegas | 0.6 | 0.4 | 0.0 | SEP | 1.5 | MAY |
| 5. Rachel | 18 | 25 | 0.9 | FEB | 77 61 | APR AUG |
| 6. Tonopah | 0.9 | 0.6 | 0.25 | FEB | 2.3 | JUN |

SEASONALITY

RANGE
AUG 0.6 - 18

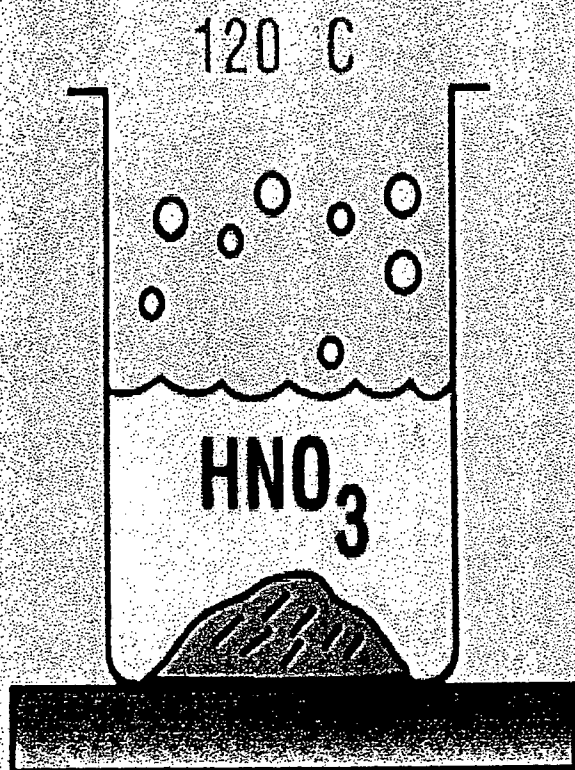
45



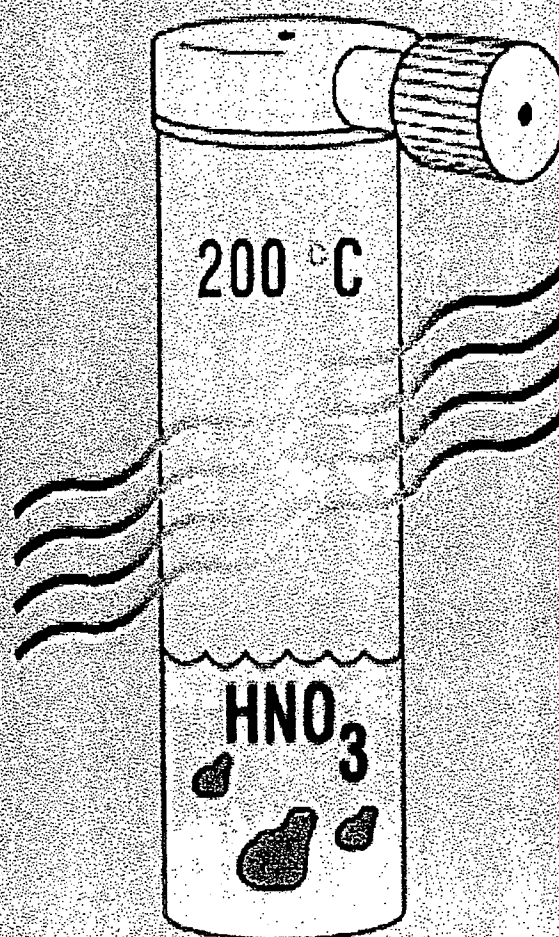
SECTION I.



Sampling & Radiochemical Analysis



Hot Plate



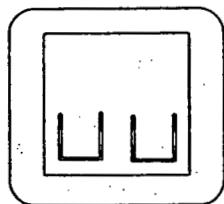
**CEM Closed Vessel
and Microwaves**

METHOD FLOWCHART

8" x 10" Air Filters
(wt. 5-10 grams)

HIGH-VOLUME AIR SAMPLING

2)



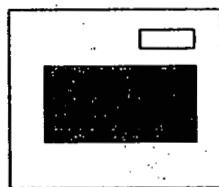
DRY ASHING @500 deg-C FOR 24-36 HOURS
(destroy organics / pre-cond. filter)

3)



PRE-DIGESTION (ROOM TEMPERATURE)
1. Aqua Regia
2. HF

4)



MICROWAVE-ENHANCED DIGESTION
2 SEQUENTIAL RUNS ~ 20 MINUTES/EACH

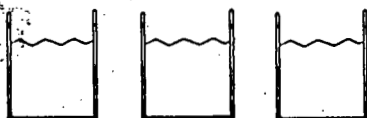
(TEMP. 80 - 160 deg-C)
(PRESS. 60 - 160 psi)

5)



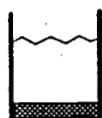
DRY @ LOW TEMPERATURE (REMOVE HF)

6)



RE-DISSOLVE / MILD DIGESTION
(CLEAR SOLUTION if)

7)

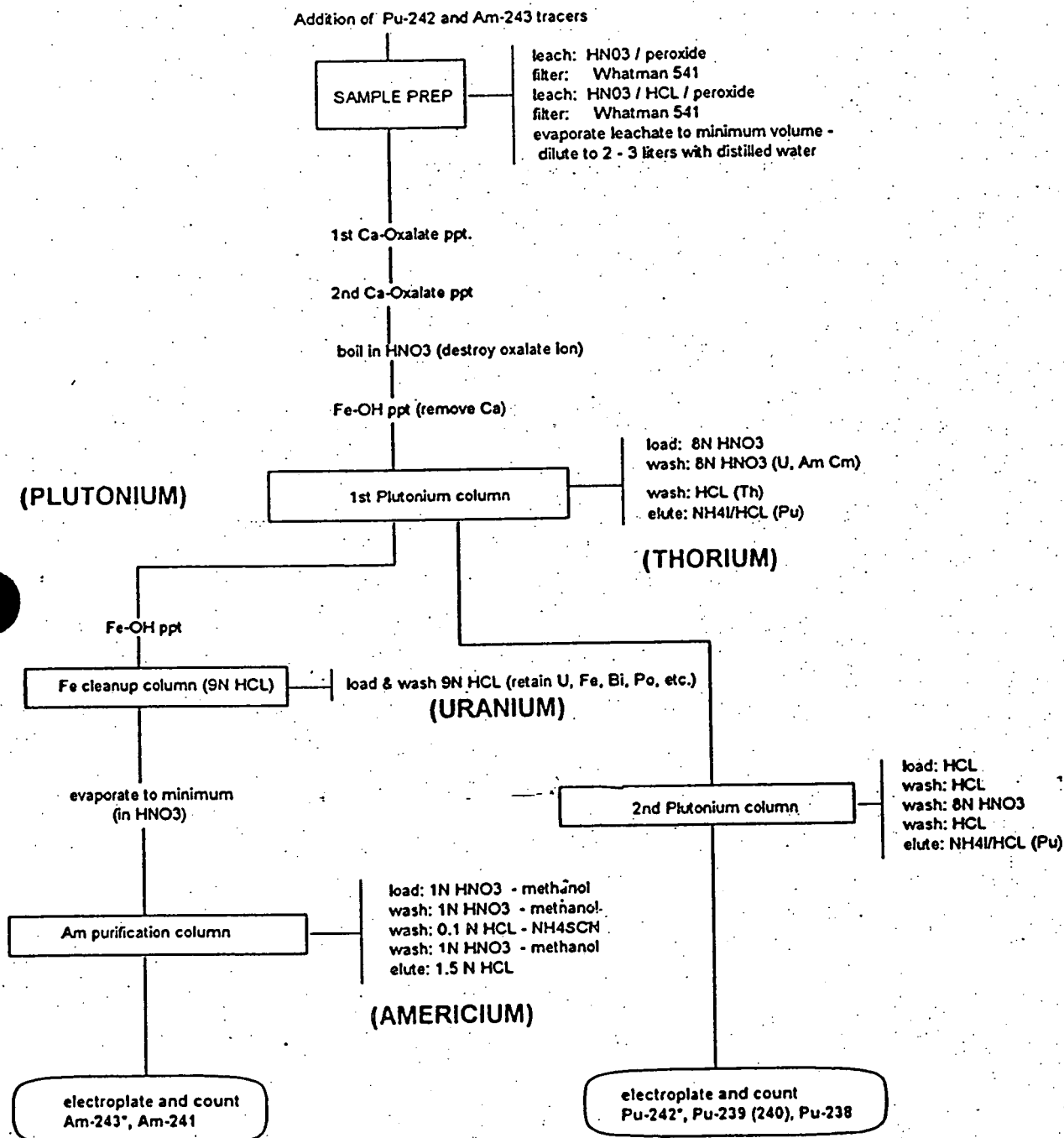


CONCENTRATION BY CO-PRECIPITATION
(FeOH, basic) or Ca-Ox (acidic)

ANALYZE (Pu, U, Am, Th)

UB

FLOWCHART FOR THE SIMULTANEOUS DETERMINATION OF PLUTONIUM AND AMERICIUM BY ALPHA SPECTROSCOPY



SYS\$SYSDEVICE: [USER.ALPHA.ARCHEIVED] ACAL_1_11-OCT-1997.CNF: 2

Spectrum:

Title:

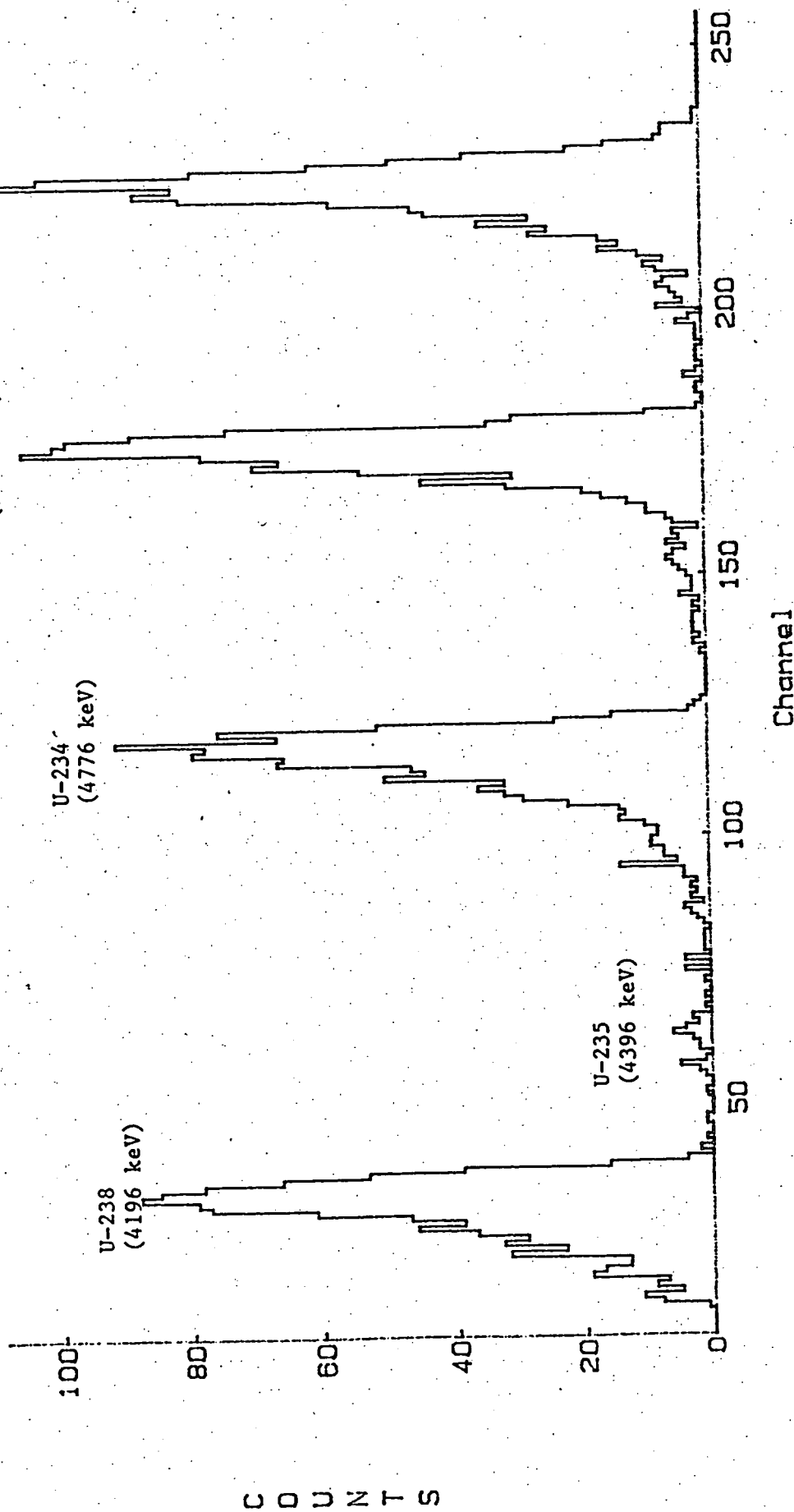
Sample Title:

ALPHA DETECTOR A1 - ENERGY CALB. SPECTRUM

(range approx. 4 to 6 MeV)

Am-241
(5486 keV)

Pu-239
(5155 keV)



Start Time: 11-OCT-97 19:13 Sample Time: 1
 Real Time: 0 01:00:06.00 Sample ID:
 Live Time: 0 01:00:05.00 Sample Type:

FWHM Parameters:
 Offset: -7.00E+00
 Slope: 2.00E+00

PLUTONIUM SPECTRUM

Spectrum: MCA0: [ALPHA]SYSTEMA2\$1

Title:

Sample Title: PU-2 RAC

Pu-242

~4.9 MeV

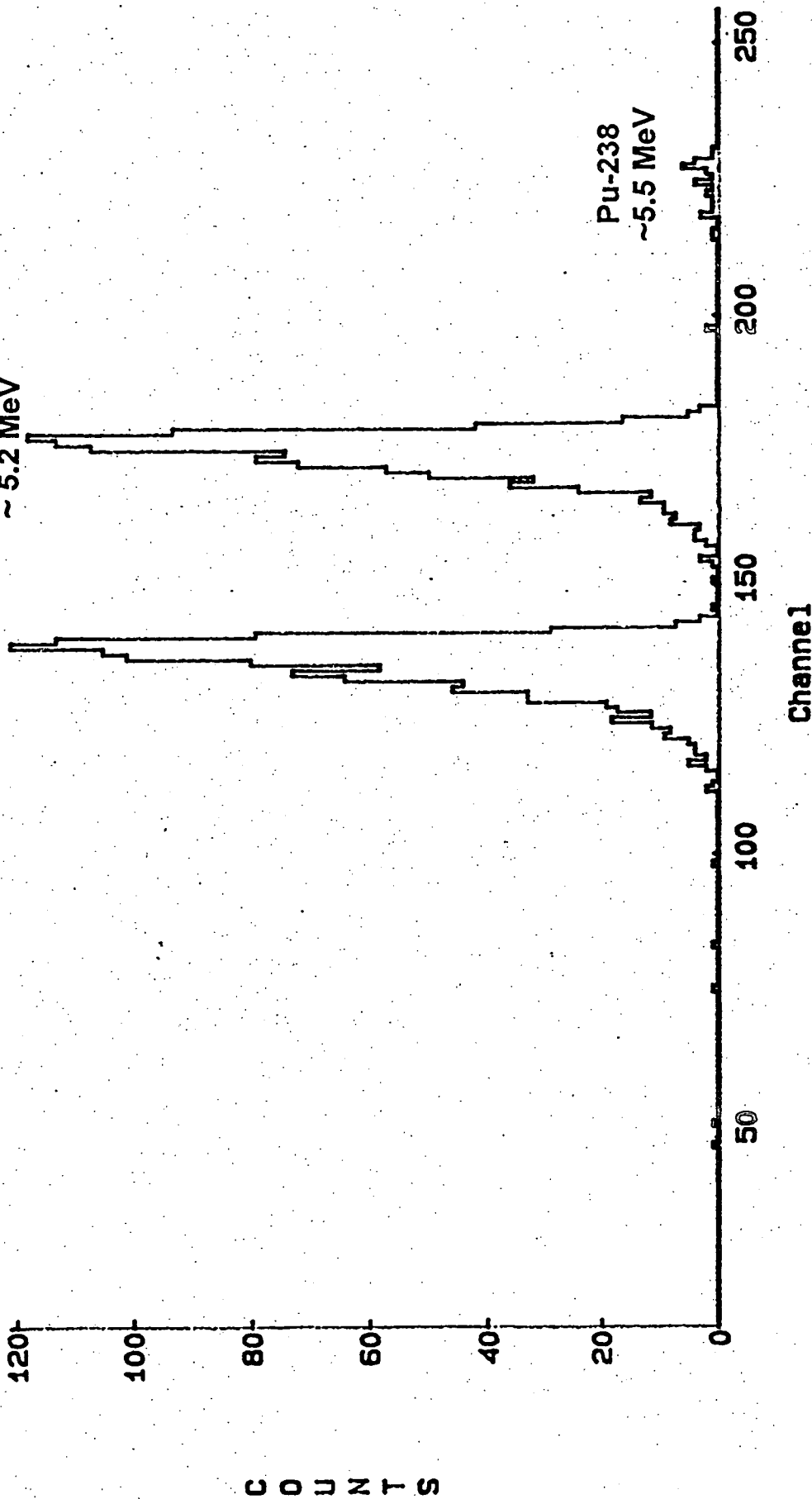
(Tracer)

Pu-239

~5.2 MeV

Pu-238

~5.5 MeV



Start Time: 10-MAR-98 16:40

Real Time: 0 16:40:04.00

Live Time: 0 16:40:03.00

Sample Time:

Sample ID: 2

Sample Type:

FWHM Parameters:

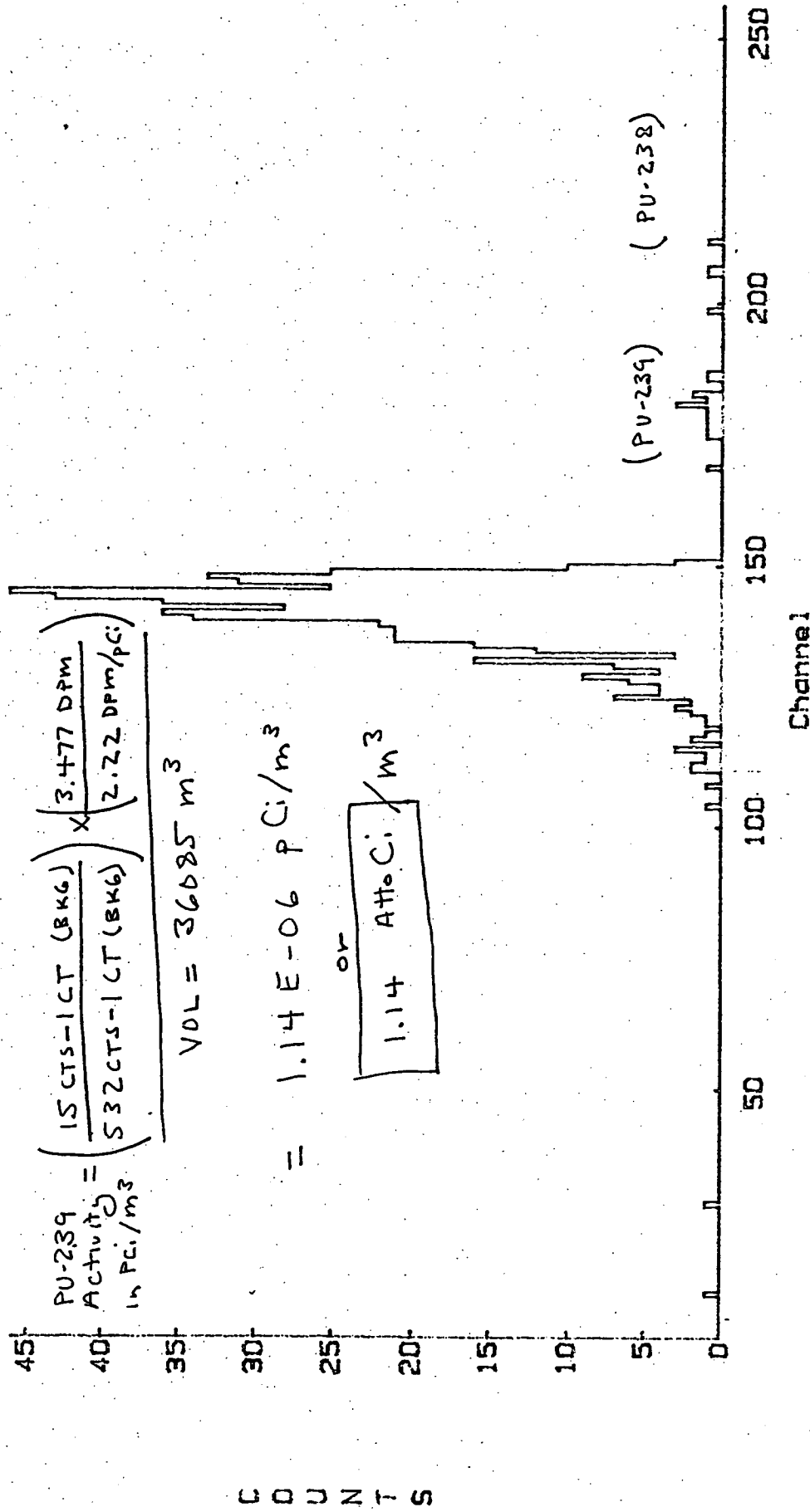
Offset: -7.00E+00

Slope: 2.00E+00

Spectrum: MCAD: [USER]SYSTEMA6\$1

Title:

Sample Title: LATHROP WELLS HI-VOL (2ND COUNTING)
(PU-242)



Start Time: 24-JUL-91 13:25

Real Time: 0 16:40:03.00

Live Time: 0 16:40:03.00

Sample Time: 24-JUL-91 00:00

Sample ID: 8

Sample Type:

FWHM Parameters:

Offset: 0.00E+00

Slope: 1.85E+00

53

Spectrum : DKA200:[ALPHA.ALUSR.ARCHIVE.S]S_PU9819\$002-718267_PU.CNF;1

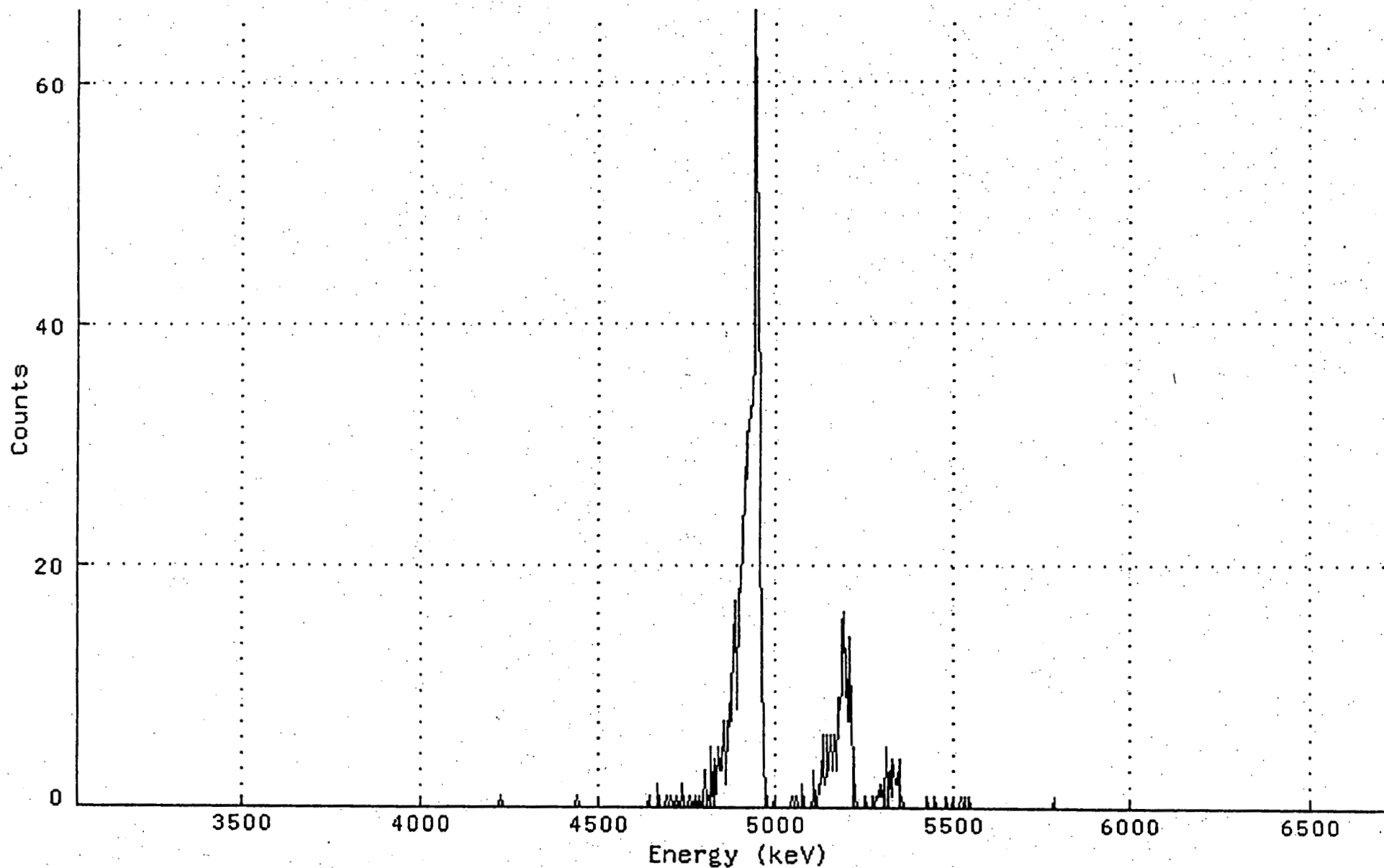
Title : 002

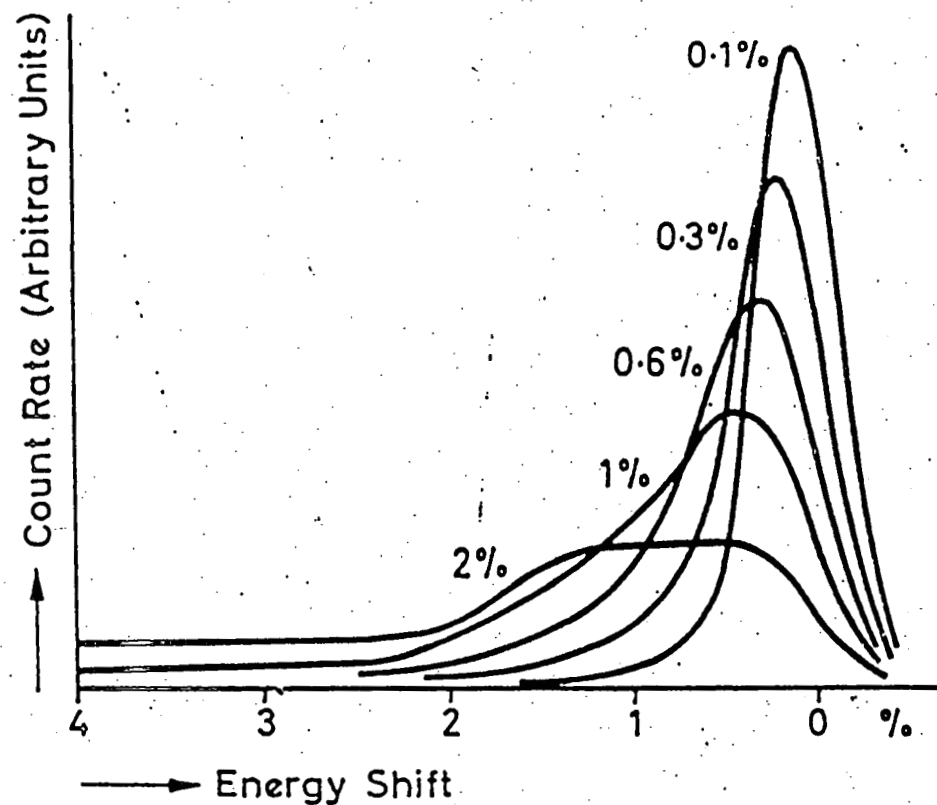
Sample Title: pu-2 hivol

Start Time: 22-FEB-1999 15:54 Sample Time: 25-JAN-1999 00:00 Energy Offset: 3.03121E+03

Real Time : 0 16:40:01.00 Sample ID : 002-718267 Energy Slope : 3.86966E+00

Live Time : 0 16:40:01.00 Sample Type: PU Energy Quad : -2.26153E-04





Influence of sample thickness on position and shape of the measured α -line of ^{239}Pu . The parameter plotted is the sample thickness as a percentage of the maximum range



SECTION II.

Field Survey Methods

FIDLER SURVEY INSTRUMENT



- **Characteristics:**
 - Thin NaI detector w/low-bkg beryllium window - ratemeter
 - Capable of detecting low-energy gamma rays (Am-241 & Pu-238) with fair sensitivity & spectral separation
 - Good at detecting "Hot Spots" because of flexibility in survey techniques (scan vs. accumulate)

- **Example of Use**

- Support Space Shuttle Launches
Radioisotope Thermoelectric
Generators [RTG's] containing
Pu-238 (17 Kev gamma)

- **Disadvantages**

- Sensitive to changes in Nat.
background (Radon daughters)
- Most suitable in prompt-deposition
scenarios (radiological accidents)
where relatively uniform surface
deposition can be assumed &
weathering-in has not occurred
- Not particularly durable (~ \$5 K ea.)

 **DESERT RESEARCH INSTITUTE**
UNIVERSITY OF NEVADA SYSTEM

**RADIONUCLIDES IN SURFACE SOIL
AT THE NEVADA TEST SITE**

**STATE DOC.
UNLV LIBRARY**

by

Richard D. McArthur

August 1991

WATER RESOURCES CENTER

Publication #45077

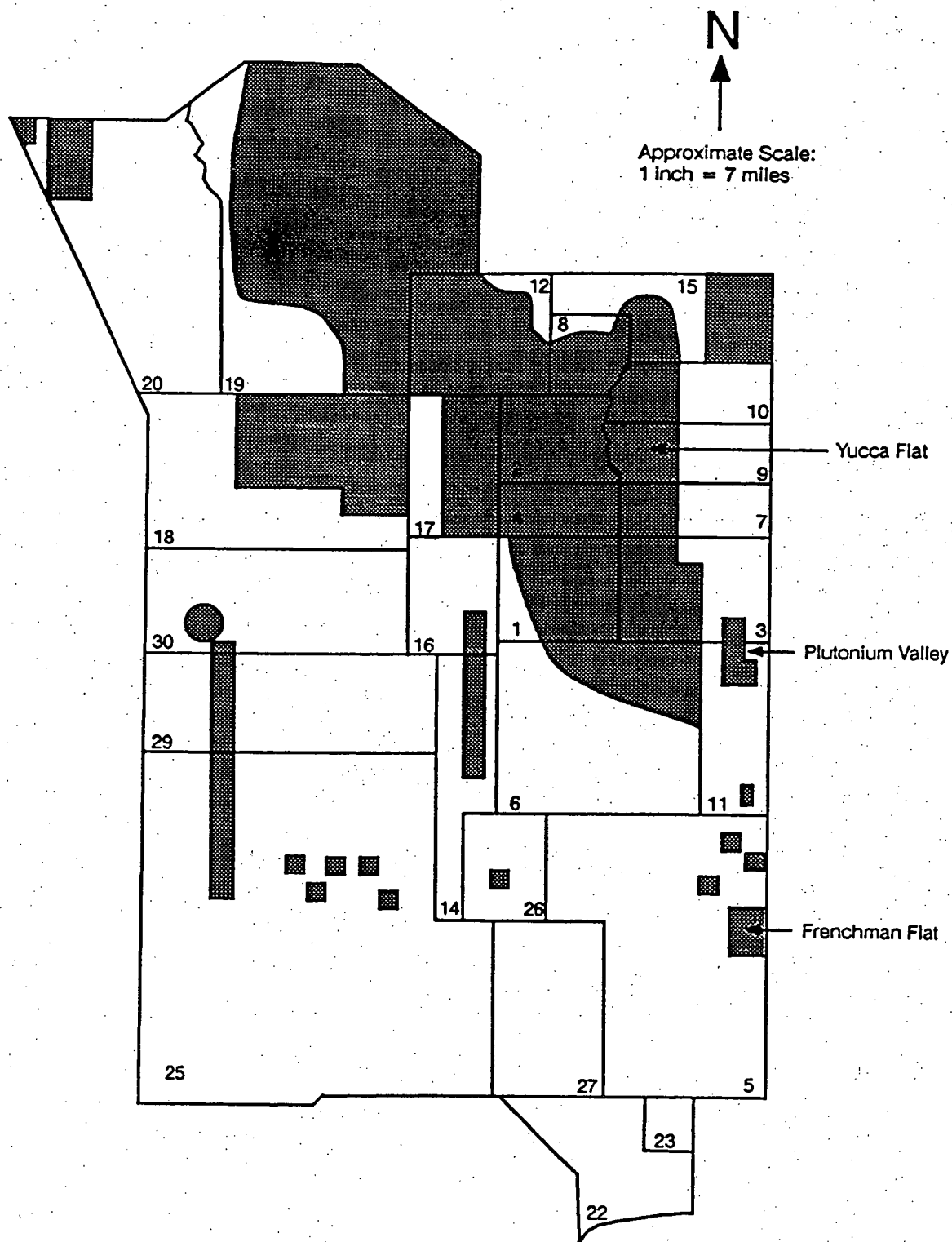


Figure 1. Portions of the NTS surveyed by the RIDP.

TABLE 5. ESTIMATED INVENTORIES OF MAJOR MANMADE
RADIONUCLIDES IN NTS SURFACE SOIL AS OF JANUARY 1, 1990

| Area | Radionuclide Inventory (Ci) | | | | | | | | |
|-------|-----------------------------|-------------------|-----------------------|------------------|-------------------|------------------|-------------------|-------------------|-------------------|
| | ²⁴¹ Am | ²³⁸ Pu | ^{239,240} Pu | ⁶⁰ Co | ¹³⁷ Cs | ⁹⁰ Sr | ¹⁵² Eu | ¹⁵⁴ Eu | ¹⁵⁵ Eu |
| 1 | 4.2 | 6.5 | 24. | 1.1 | 8.8 | 15. | 15. | 0.1 | 0.5 |
| 2 | 2.9 | 8.6 | 22. | 1.2 | 24. | 46. | 14. | 0. | 0.4 |
| 3 | 4.6 | 3.1 | 37. | 1.0 | 12. | 33. | 18. | 0.1 | 0.5 |
| 4 | 6.6 | 13. | 40. | 1.6 | 12. | 13. | 9.1 | 0. | 0.2 |
| 5 | 0.6 | 0.1 | 4.8 | 0.6 | 0.4 | 0.9 | 10. | 0.2 | 0. |
| 6 | 1.7 | 3.3 | 8.4 | 0.2 | 2.8 | 3.5 | 0. | 0. | 0. |
| 7 | 2.2 | 0.6 | 16. | 1.0 | 5.2 | 9.2 | 22. | 0.2 | 0.3 |
| 8 | 17. | 8.0 | 110. | 5.7 | 42. | 25. | 4.4 | 0. | 0.6 |
| 9 | 4.2 | 2.2 | 89. | 0.7 | 8.7 | 13. | 23. | 0.2 | 0.3 |
| 10 | 19. | 19. | 110. | 9.7 | 84. | 55. | 2.2 | 0.3 | 5.0 |
| 11 | 3.3 | 0.5 | 29. | 0. | 0.5 | 0.3 | 0. | 0. | 0. |
| 12 | 5.7 | 8.5 | 39. | 1.2 | 20. | 17. | 0. | 0. | 0. |
| 15 | 8.0 | 7.8 | 63. | 0.3 | 19. | 22. | 0. | 0. | 0. |
| 16 | 0.7 | 1.5 | 3.7 | 0.1 | 2.9 | 3.7 | 0. | 0. | 0. |
| 17 | 2.8 | 4.5 | 18. | 1.0 | 15. | 19. | 0. | 0. | 0. |
| 18 | 19. | 5.6 | 100. | 0.7 | 10. | 17. | 1.1 | 0.1 | 0.8 |
| 19 | 21. | 32. | 140. | 1.1 | 36. | 31. | 0. | 0. | 0. |
| 20 | 23. | 30. | 41. | 7.9 | 5.5 | 4.3 | 13. | 1.6 | 4.8 |
| 25 | 0. | 0. | 0. | 0. | 0.2 | 0.1 | 0.4 | 0. | 0. |
| 26 | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |
| 30 | 3.2 | 4.5 | 14. | 0.8 | 1.5 | 1.3 | 0.7 | 0.1 | 0.2 |
| Total | 150. | 160. | 910. | 35. | 310. | 330. | 130. | 2.8 | 14. |

1. ¹³⁷Cs was almost always present in measurable amounts, so the few ULVs were treated as valid data.
2. ²⁴¹Am and ⁶⁰Co were assumed to be present at one-half the ULV, as determined by inspection of the data. For example, if the ²⁴¹Am values in a region tended to be ULVs in the 25 to 35 nCi/m² range, a value of 15 nCi/m² was assumed.
3. The three europium isotopes were found only relatively close to a GZ. They were assumed not to be present at all in regions where only ULVs were reported. Some previous inventory estimates for these radionuclides were therefore not used in making Table 5.

Inventories of the plutonium isotopes and ⁹⁰Sr were estimated from ²⁴¹Am and ¹³⁷Cs inventories using the radionuclide ratios from the nearest GZ area.

Additional recalculation was necessary for Yucca Flat because the original estimates in Reports 1, 2, and 3 were not made for separate NTS areas.

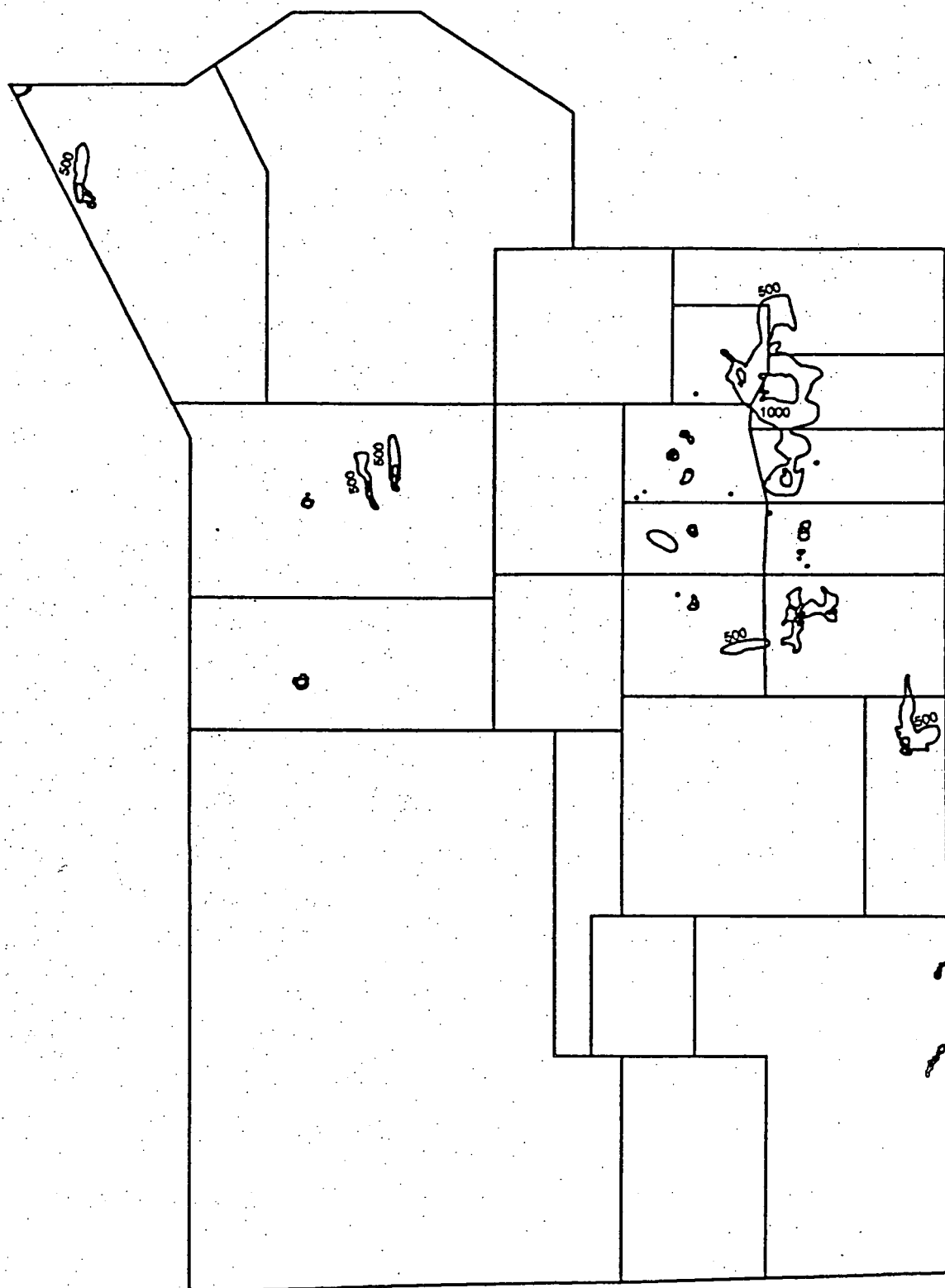


Figure 4. Distribution of $^{239,240}\text{Pu}$ on the NTS as of January 1, 1990. Isopleth levels are 500, 1,000, and 10,000 nCi/m².

Figures 2 through 10 are only intended to give a general picture of the overall distribution of soil radioactivity on the NTS. The small size of most contaminated areas relative to the size of the NTS makes it impossible to label most of the isopleths without obscuring this picture. The values of any unlabeled isopleth can be inferred by using the following guidelines:

- Isopleths are drawn for 100 nCi/m², 1,000 nCi/m², and 10,000 nCi/m² for all radionuclides except ^{239,240}Pu, where a 500 nCi/m² isopleth replaces the 100 nCi/m² one. (Because the ^{239,240}Pu to ²⁴¹Am ratio exceeds 5 in most areas and the smallest ²⁴¹Am measurements are around 40 nCi/m², few calculated ^{239,240}Pu values are less than 200 nCi/m².)

- The general distribution pattern is the same for all radionuclides. In the southern and western parts of the NTS, concentrations are less than 100 nCi/m² except in isolated areas. Only ¹³⁷Cs and ⁹⁰Sr exceed 100 nCi/m² over a broad region in the northeast corner.

- All isopleths behave "normally," with larger-valued isopleths contained within smaller-valued ones.

Larger-scale, more detailed maps for any contaminated region can be found in the five RIDP reports.

Exposure Rate

The total exposure rate from gamma radiation at each location was calculated by first multiplying the decay-corrected concentration of each radionuclide by a radionuclide-specific factor that converts the concentration in nCi/m² to exposure rate in μR/h. The exposure rates due to the individual radionuclides were then added to give a total for each location. The procedures for determining the conversion factors and calculating the exposure rates were provided by L. Anspaugh (LLNL), the Scientific Director of the RIDP. Appendix B describes the calculations in detail.

Figure 11 is a map showing the 96 measurement locations where the exposure rate exceeds 100 μR/h. At only 10 locations does the exposure rate exceed 500 μR/h. All 10 are in Area 20, two near the Schooner GZ and 8 near the Palanquin GZ. Four Palanquin locations exceed 1,000 μR/h, with the maximum value being 1,600 μR/h.

^{239,240}Pu Concentration

The value of 500 pCi/g of ^{239,240}Pu in soil is currently being considered as a criterion for fencing off contaminated areas at the NTS. Measurements of ^{239,240}Pu in nCi/m² are converted to pCi/g by the formula

$$\text{pCi/g} = 0.1 \times (\text{nCi/m}^2) \times \alpha / 1.5,$$

where 1.5 is the soil density in g/cm³. Thus for $\alpha = 0.05/\text{cm}$, 500 pCi/g is equivalent to 150,000 nCi/m²; for $\alpha = 1.0$, the value is 7,500 nCi/m².

Figure 12 shows the 133 locations of *in situ* measurements where the $^{239,240}\text{Pu}$ concentration exceeds 500 pCi/g. The highest values are near the Oberon GZ in Area 8, where two measurements exceed 100,000 pCi/g (the maximum is 320,000 pCi/g). Four other points at Oberon, one at Wilson, one at Quay, and four at Little Feller II exceed 10,000 pCi/g.

The highest concentration calculated for a Plutonium Valley location was 3,000 pCi/g. However, concentrations are undoubtedly much higher in the immediate vicinities of the four blast centers. Also, substantial amounts of plutonium are known to be present in the soil in regions outside the NTS boundary at Frenchman Lake (Area 5) and the Schooner site (Area 20).

UNCERTAINTY OF THE RESULTS

The project operations plan (Kordas and Anspaugh, 1982) specified an overall goal of providing "a final inventory that is known with 95% confidence within at least a factor of two." The project scientists feel that this level of precision has been attained, but this assessment derives more from their expert judgment than from any numerical analysis. The process by which the inventory estimates are produced is complex, and uncertainty enters it at a number of points. A thorough evaluation of how these uncertainties interact to affect the precision of the final results is not currently practicable.

Sources of Uncertainty

Listed below are the major sources of uncertainty in the inventory estimates and distribution maps and an indication of their importance.

Counting error. The random nature of radioactive decay is an intrinsic source of variation in any measurement of radioactivity. The GAMANAL program calculates the counting error as a percentage of the activity of each radionuclide. Reported values typically range from 3 to 40 percent. High activities are usually measured with a smaller percent error (but larger absolute error) than low activities.

Physical parameters. GAMANAL takes into account air density, soil density, and soil moisture content when calculating radionuclide activities. As noted on page 7, the same values of these parameters were used for the analysis of the *in situ* measurements from every survey. Differences between the values used and the actual values for a given area could cause an error of a few percent in the calculated activities.

Inverse relaxation lengths. The inverse relaxation lengths used in GAMANAL were averages of several values calculated from soil profiles. The calculated inverse relaxation lengths are usually quite variable, so choosing a single representative value entails a high degree of uncertainty. The computed conversion factors are extremely sensitive to the value of the inverse relaxation length, especially at low energies (see Report 1, p. 20).

Radionuclide ratios. The ratios used to estimate inventories of ^{238}Pu , $^{239,240}\text{Pu}$, and ^{90}Sr were averages of values measured in soil samples. The number of samples involved was usually small, and the variability in the measured ratios was usually large, so the values used to estimate inventories have a high uncertainty. Errors in the ratios affect the inventory estimates directly, so if the average ratio is too high by 50 percent, the inventory estimate will also be too high by 50 percent.

Upper Limit Values. When ULVs were used in a data set, they were treated as valid measurements, so the resulting estimates are larger than they should be. The areas within which inventories were estimated were usually set up to include as few ULVs as possible, so the error involved in the total inventory figures is probably negligible.

Sampling error. Sampling error results from estimating the total inventory in an area from measurements at relatively few locations. The size of the sampling error depends on the distribution of radioactivity in the area, the number of measurements, and how the measurement locations are chosen.

The only RIDP study areas where the sampling variability can be estimated directly are the four GZs in Area 18, where importance sampling was used to select the measurement locations (Report 4). The sampling standard deviation at these sites ranged from 5 percent to 40 percent of the total inventory.

Most of the other GZ areas were sampled on a regular grid, with 400-foot or 500-foot grids being used in the regions of highest activity. The sampling variability of the grid design at Frenchman Lake was estimated to be about 20 percent (Report 5, pp. 46-48), and the variability at similar GZ areas is probably comparable. The sampling variability is probably somewhat larger at safety shot sites like those in Plutonium Valley, where contamination occurs in discrete particles that are typically not as uniformly distributed around the GZ as is the radioactivity from a fission explosion.

Location. The locations of the *in situ* measurements were usually determined with a microwave ranging system. The errors in the computed locations can be anywhere from 10 feet to 250 feet or more, depending primarily on the relative positions of the location and the two microwave transponders. The effect of such errors on the inventory estimates and distribution maps is hard to determine, but it is believed to be relatively small compared to other uncertainties.

Comparison with Earlier Studies

During the course of the RIDP, surveys were made of four regions that had previously been studied by researchers from the Nevada Applied Ecology Group (NAEG). The estimates of $^{239,240}\text{Pu}$ inventory obtained by both groups for these regions are shown in Table 6. While the estimates are not entirely comparable because of differences in the areas surveyed, the comparison is still of some interest.

TABLE 6. RIDP AND NAEG ESTIMATES OF ^{239,240}Pu INVENTORY

| Region | Size of Region (km ²) | | Inventory (Ci) | |
|---------------------|-----------------------------------|------|----------------|----------|
| | RIDP | NAEG | RIDP | NAEG |
| GMX | 0.97 | 0.13 | 1.4 | 1.5 |
| Plutonium Valley | 8.7 | 4.8 | 29 | 36 |
| Palanquin/Cabriolet | 12 | -3.4 | 48* | 13* |
| Little Feller II | 0.87 | 1.1 | 27 | 25 to 31 |

*Includes ²⁴¹Am inventory

References: RIDP Reports 4 and 5; Gilbert, 1977; Gilbert *et al.*, 1985.

GMX. The NAEG estimate was based on the analysis of 111 soil samples. Of the 65 RIDP *in situ* measurements at GMX, 8 were within the NAEG study area. Using the average of these eight measurements and a ^{239,240}Pu/²⁴¹Am ratio of 7.2 (the average from three RIDP soil samples) leads to an estimate of 1.1 Ci of ^{239,240}Pu in the NAEG area. If the NAEG's Pu/Am ratio of 10.3 (based on 89 samples) is used instead, the estimated inventory for the NAEG study area is 1.4 Ci, in good agreement with the NAEG estimate.

Plutonium Valley. The area surveyed by the RIDP includes all but the southern edge of the NAEG study area. The RIDP found a substantial amount of ^{239,240}Pu, about 7 Ci, north and east of the NAEG area. Consequently, the RIDP estimate for the NAEG area is about 22 Ci, somewhat less than the NAEG estimate. The NAEG estimate was based on 205 soil samples, while the RIDP estimate was based on 128 *in situ* measurements.

Palanquin/Cabriolet. The area surveyed by the RIDP was twice as large as that surveyed by the NAEG, which partly explains the difference in inventory estimates. In addition, the NAEG did not include the regions within 500 feet of the GZs in its survey. On the other hand, the NAEG was able to sample in the rocky area near the two GZs where the RIDP vehicle could not go. The difference in regions surveyed makes a detailed comparison of the data difficult.

Little Feller II. The original RIDP estimate in Report 4 was three times the NAEG estimate. Investigation of the discrepancy led to discovery of a major error in the calculations; see Appendix C for details. The corrected RIDP estimate (based on 54 *in situ* measurements) agrees closely with the NAEG estimate (based on analyses of 712 soil samples).

The results of these comparisons thus tend to confirm the accuracy of the *in situ* method as used in the RIDP.



IN-SITU MONITORING



- **Advantages:**
 - Detection of multiple radionuclides
 - Integrates deposition (+/-)
 - Relatively fast & less cost per area
- **Disadvantages (Sources of Uncertainty):**
 - [As previously listed]
 - ANSI standard in development



***** DISCUSSION *****

- **Compared Radiochemical and Field Methods**
- **Sources of Uncertainty**
 - **sampling vs. analytical errors**
 - **collection efficiency (Air)**
 - **Limitations of FIDLER Surveys**
 - **In-situ factors (depth, density)**
- **Rocky Flats Literature**
 - **Soil Survey(s) (Ibrahim & Whicker)**
 - **Isotope "fingerprinting" (Efurd)**
 - **Regional Background**
 - **Air Sampling (COMRAD)**



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**RFETS 903 Pad Lip Area and
Americium Zone Radiological Characterization
by
ISOCS/ *In Situ* Gamma Spectroscopy**

Larry Umbaugh -- Canberra Industries, *presenter*

**Lee Booth, Gordon Madison,
Paul A. Wojtaszek, Ed Gulbranson -- Canberra Industries**

Steve Paris, Mark Wood, Steve Luker -- R.M.R.S.

Presented to the:

RFETS Radiological Soil Action Level Oversight Panel

August 12, 1999



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INTRODUCTION

In Situ gamma spectroscopy can be a valuable tool for supporting decontamination and decommissioning (D&D) activities at nuclear facilities. These measurements can save money and time in the characterization, decontamination and release of buildings and grounds. The Canberra *In Situ* Object Counting System (ISOCS) is a portable gamma spectroscopy system that has been deployed at several sites performing D&D work, with successful results.

This paper describes the applications used in the characterization of the 903 PAD and American Zone and identifies specific advantages over more conventional methods.

ISOCS consists of a Ge detector (several types are available), multi-attitude cryostat which allows the detector to be pointed in any direction, an InSpector MCA and laptop PC, ISOCS shield and cart and ISOCS calibration software. The calibration software allows the user to model the object to be counted using one of a set of standard geometry templates and mathematically calculate an efficiency response for the object-detector configuration.



The user(s) generated unique efficiencies for counting sample/geometry configurations which would otherwise have been difficult or expensive to duplicate as counting standards.

The 903 Pad Project at the Rocky Flats Environmental Technology Site (RFETS) involved the assessment of the extent of surface and subsurface soil contamination resulting from past accidental releases of Pu and U. *In situ* gamma spectroscopy was selected as the preferred method for evaluating the areal surface contamination because of the method's ability to directly measure large surface areas in short count times and to obtain immediate results. Target nuclides for *in situ* measurements were Am-241, U-235 and U-238, with Pu derived from Am-241. Because of the low energy photon emissions from Am-241 and U isotopes, careful modeling of the soil contamination, which addressed vertical distributions, soil chemical composition and moisture content, was critical. Over 1100 measurements were completed, with results providing



distributions as expected and showing excellent agreement with soil sampling results.

SOIL MEASUREMENTS AT RFETS

In situ gamma spectroscopy has been used for assessment of radioactive materials in soils for a number of years. At the Rocky Flats Environmental Technology Site (RFETS), the 903 Pad Project required such an assessment. The goal of this project was to provide detailed information regarding the extent of soil contamination on and in the vicinity of, the 903 Pad site, so that remedial action options can be evaluated, developed and implemented.

A sampling plan, developed by RFETS and reviewed and approved by oversight and regulatory groups, formed the basis of the project scope of work. The plan specified that *in situ* gamma spectroscopy be used to characterize the study area of approximately 3 acres. A triangular grid pattern 10 meters on a side was used with measurement points at the grid intersections. The *in situ* measurement field of view was a 10 meter diameter circular plane.

Measurements were performed at a height of one meter with the detector collimated to restrict the field of view to 10 meters. This measurement pattern provided 78% coverage of the study site.



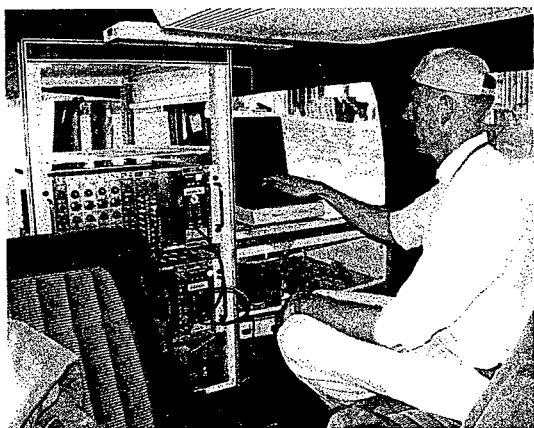
The sampling plan identified nuclides of interest, which included Am-241, U-235 and U-238, with required detection limits of 1, 0.5 and 5 pCi/g, respectively. Pu was derived from Am-241 using a previously established ratio for Pu 239/240 to Am-241 of 7:1. The vertical distribution of contaminants in the surface soils had been established in prior studies and showed that approximately 80% of the Pu and U contamination was contained in the top 5 cm (2 inches) of soils, with highest concentrations near the surface and levels decreasing rapidly with depth. These studies also provided data on the chemical composition and moisture content of RFETS soils.

The ISOCS calibration software was used to calculate an efficiency appropriate for this application. The model used was the circular plane source, with a diameter of 10 meters, a vertical distribution containing 66% of the activity in the top 3 cm and 33% of the activity in the next 2 cm, a detector height on one meter and soil composition containing small amounts of Fe, Al and Mg and a density of 1.3 g/cc. Alternative models, with different horizontal and vertical distributions and soil compositions were tested to



determine an approximate range of uncertainties in the selected model.

When using the modeled efficiency, a count time of about 20 minutes was needed to meet the required detection limits. The field measurement locations were documented with a commercial global positioning system (GPS). Soil samples were collected from six grid locations covering a range of activities, and analyzed at a commercial laboratory using both gamma spectroscopy and alpha spectroscopy. Field measurements commenced in September, 1998, and continued through March, 1999. Most of the study site was posted as a Radiological Controlled Area (RCA) and required protective clothing and access control measures. The *in situ* equipment was contained in an all terrain vehicle within the RCA, except for the detector carts and GPS mount.



Canberra provided a complete measurement service, which included *in situ* equipment and operational personnel, health and safety coverage, soil sampling and packaging, grid layout and GPS measurements and electronic data reporting. Over 1100 sample measurements and 200 QC measurements (duplicates, controls and backgrounds) were completed and

reported, allowing RFETS to meet performance goals. The ability to obtain immediate results was critical in bounding and limiting the scope of the study to those areas which exceeded the site action levels.

A comparison to conventional soil sampling and analyses showed excellent agreement when comparable sampling and measurement protocols were used. However, *in situ* measurements were shown to be less expensive and more timely. For a complete *in situ* service, as described above, the estimated total cost for each grid measurement was \$300. For a comparable soil sampling program (composites of multiple samples from each grid), the estimated cost is \$650, more than twice the cost of *in situ*. (This cost could have been reduced to \$420 per grid if time were of no consideration, still 30% more than *in situ*).

CONCLUSIONS

Decommissioning of nuclear facilities requires characterization of systems, buildings, and the grounds surrounding them. This has been performed using ISOCS as one of the key tools. Modeling and *in situ* counting of complex project components such as soil, tanks, traps, glove boxes, filter banks and piping eliminates the need to dig up soil samples (thus spreading the contamination), opening and/or dismantling systems for characterization purposes. Estimates of levels of external and internal contamination obtained with ISOCS measurements have been consistent with other methods where comparisons are available.

Features

- Provides accurate efficiency calibrations for a wide range of geometries without the need for expensive calibration sources.
- Yields results within a few percent of those produced by the traditional calibrated source method.
- Eliminates the cost of purchasing standard sources, creating custom distributions, and radioactive waste disposal.
- Operates with any size or type of Germanium detector which has been characterized by Canberra.
- Ideal for *in situ* applications, where large and various sample types are often encountered.
- Includes predefined geometry templates for nine (9) common sample and container shapes.
- Includes predefined templates for the three (3) collimators included in ISOCS Shield Systems.
- Custom geometries are offered to meet special application needs.
- Allows accurate qualitative and quantitative gamma assays of most any size or type of sample.
- Easy to use fill-in-the blank operator interface
- Only a few physical sample parameters (e.g. Size, Distance from Detector, etc.) are needed to tailor a template to a sample.
- Ability to vary assumed sample characteristics (e.g. Density, Container Wall Thickness, etc.) makes it ideal for "What if...?" analyses.
- Easily launched from a desktop icon while running Genie-PC Spectroscopy Assistant or PROcount.
- Resulting calibrations may be stored, recalled, and used just like those generated by traditional calibration techniques.

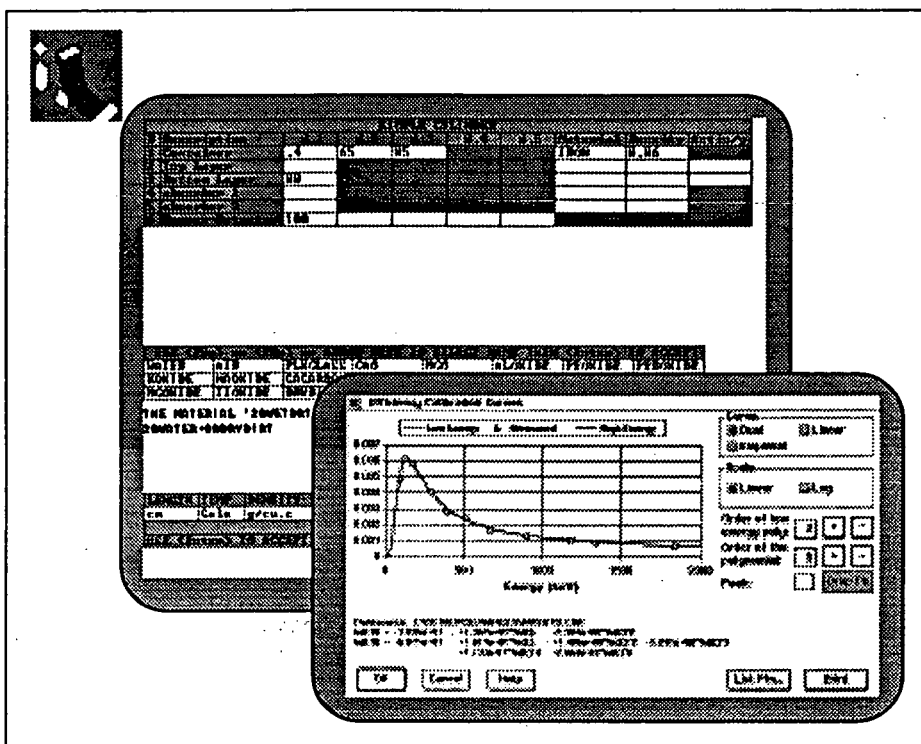


Figure 1: ISOCS Calibration Software is launched from the Desktop, used for Data Entry, and then generates the Genie-PC Efficiency Curve.

Description

The Model ISOXSW ISOCS (*In Situ* Object Counting System) Calibration Software brings a new level of capabilities to Germanium gamma sample assays by eliminating the need for traditional calibration sources during the efficiency calibration process. By combining the detector characterization produced by the MCNP modeling code, mathematical geometry templates, and a few physical sample parameters, ISOCS Calibration gives you the ability to produce accurate qualitative and quantitative gamma assays of most any sample type and size (Figure 1).

In addition to saving money by eliminating the need to purchase (and later dispose of) many calibration sources, ISOCS Calibration also saves time. Instead of hours spent in traditional source preparation and long calibration counts, an ISOCS Calibration for a new geometry requires only a few seconds of computer calculations.

The secret to this capability is twofold:

1. The energy/efficiency/spatial response profile of the Ge detector has been characterized by Canberra with the well-known MCNP Monte Carlo modeling code.
2. Mathematical templates have been created for most of the sample geometries that will be encountered – planar surfaces, rectangular boxes, barrels, pipes, etc.

To a basic geometry template, add the specifics for a given sample – its size, density, distance from the detector, etc. – and the ISOCS Calibration Software generates a custom efficiency calibration specifically tailored for that detector and sample. The remainder of this document will describe how this is done and how the various standard geometries templates are used.

The Assay and Calibration Process

To better understand how the ISOCS Calibration Software is used, it's necessary to look at the complete ISOCS sample assay process. In general terms, it's as follows:

1. Count the sample. Use a detector which has been characterized by Canberra, and the Model ISOXSHLD ISOCS Shield and Collimator System, if required.
2. Select the Geometry Template which best fits the sample type (such as planar surface, rectangular box, cylinder, pipe, etc.).
3. Measure the relevant physical sample parameters required by that template (such as size, density, distance to the detector, etc.).
4. Enter these parameters into the ISOCS Calibration Software and generate an efficiency calibration for those conditions in 15 seconds, typically. Examine/modify the shape of the resultant Genie-PC calibration curve and store it.
5. Use this calibration for the analysis of the spectrum collected during the sample count in step 1, yielding a qualitative and quantitative assay of the sample.

The sample parameters recorded in step 3 are key elements to the process, for they allow the software to tailor the theoretical response of the detector for a given geometry to the specific sample being assayed. For maximum accuracy and flexibility, each template allows a wide variety of parameters to be specified.

In addition to the parameters mentioned in step 3, provisions are included for things like container wall thickness, the presence of absorbers between the source and detector, non-homogenous source location within a container, variable sample densities, and off-axis detector placement. In short, most any factor that can impact the assay may be measured and specified. If a parameter is not known, various values can be tried to determine what, if any, influence that parameter has on the results of the assay.



Figure 2: Using the ISOCS System to assay a pipe.

The Basic Geometries Included with ISOCS

The basic Geometry Templates included with the ISOCS Calibration Software can be seen on the facing page. For each, the various physical parameters that may be varied are shown as numbered callouts.

In addition to these standard templates, custom templates can be defined by Canberra to meet special application needs. And for all templates, the presence or absence of a collimator can be specified and automatically accounted for.

The basic templates and their applications are as follows:

- **Simple Box**

A basic rectangular carton or waste shipping container, a truck filled with scrap iron, or even a small building.

- **Complex Box**

The same as the Simple Box, but with a more complex sample matrix. It includes the ability to distribute the contamination across as many as four (4) layers of material and/or to place an additional concentrated source anywhere in the container. Ideal for use in "What If?" analyses of non-uniform distribution in waste assay containers.

- **Simple Cylinder**

A basic barrel, tank, or drum. In an emergency, it could also be used for a quick whole body contamination count.

- **Complex Cylinder**

The same as the Simple Cylinder, but with a more complex sample matrix. It includes the ability to distribute the contamination across as many as four (4) layers of material and to place an additional concentrated source anywhere in the container. Ideal for use in "What If?" analyses of non-uniformity in barrels and drums.

- **Pipe**

A pipe, empty or full, including material that has plated out or built-up on the inner walls, as shown in Figure 2.

- **Circular Plane**

The end of a barrel or tank, the bottom of a bottle containing a sample, or a filter cartridge. This would also be used for *in situ* measurements of ground. The radioactivity can be distributed in any manner in up to ten (10) layers of sources/absorbers.

- **Rectangular Plane**

A floor, wall, or ceiling, or soil *in situ*. The template allows for surface contamination as well as up to ten (10) layers of internal contamination behind an absorber such as paint, paneling, or a floor covering.

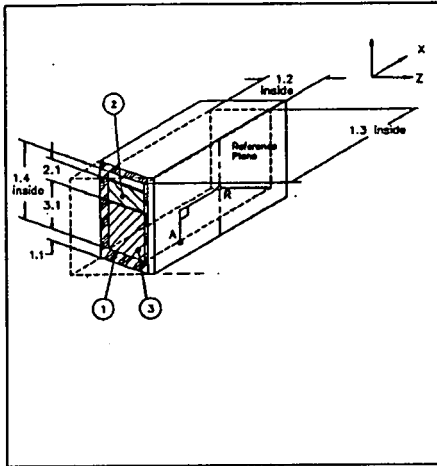
- **Well or Marinelli Beaker**

Used for well logging applications, or for standard Marinelli beakers.

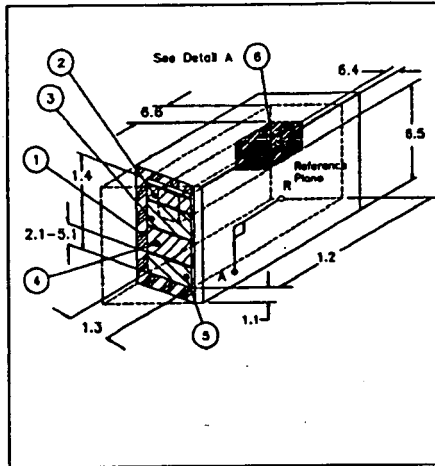
- **Sphere**

Internally contaminated spherical objects, like large pipe valves.

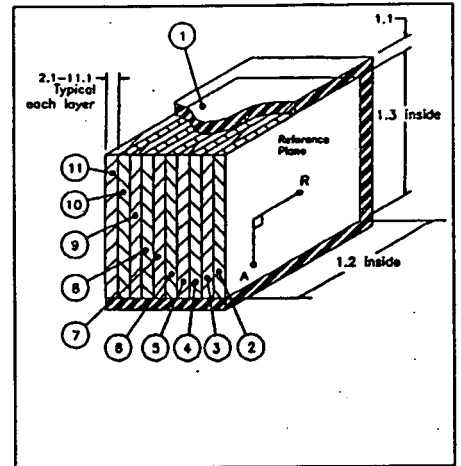
The Basic* ISOCS Calibration Templates



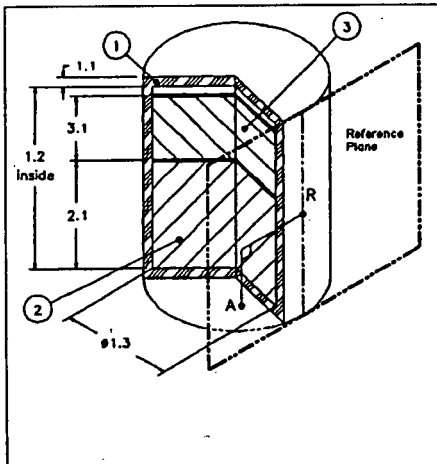
Simple Box



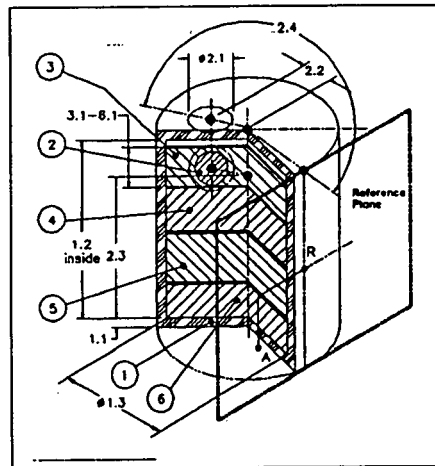
Complex Box



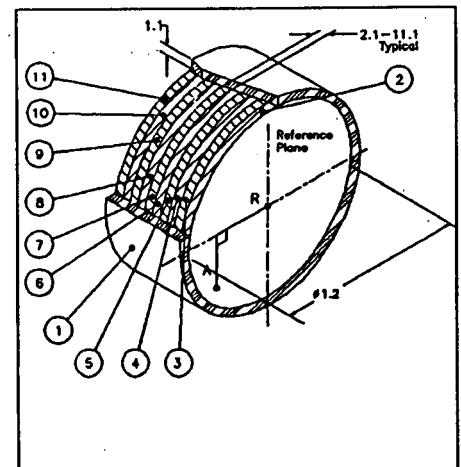
Rectangular Plane



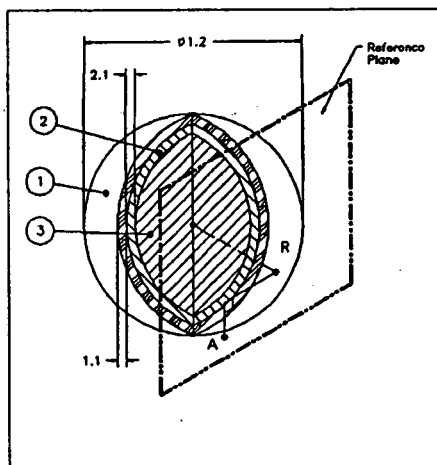
Simple Cylinder



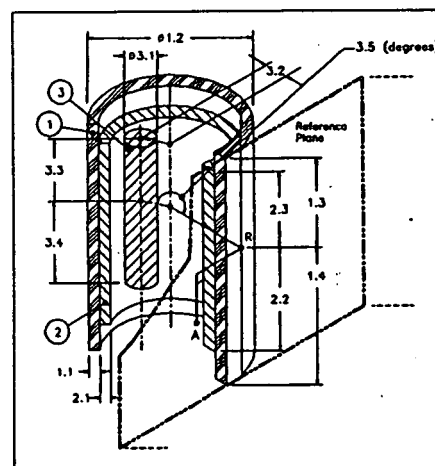
Complex Cylinder



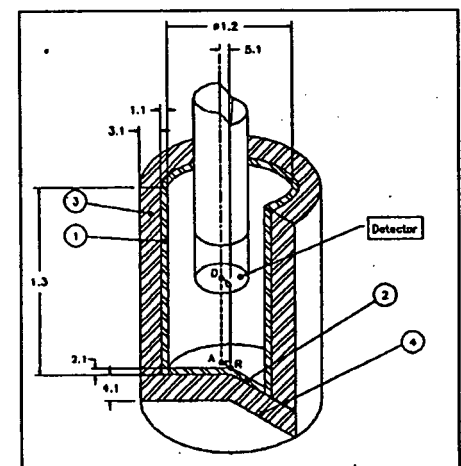
Circular Plane



Sphere



Pipe



Well or Marinelli Beaker

*Additional templates will be included as they are developed. Custom templates are also available. Consult the factory for details.

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Using the ISOCS Calibration Software

To illustrate how these templates and their related sample parameters are used, a typical ISOCS calibration will be described. It will be based upon the Simple Cylinder template, which would be the one most commonly used to assay material contained in drums.

The ISOCS calibration software is launched from a desktop icon.

Specifying the Detector and Collimator

The first step is to select the detector that used for the count. Multiple detectors can be characterized and available for use. Then select the collimator that was used, if any. This provides the calibration software with appropriate mathematical models for these devices.

| Template List | |
|---------------|-------------------------|
| 1 | CIRCULAR PLANE |
| 2 | COMPLEX BOX |
| 3 | SIMPLE BOX |
| 4 | RECTANGULAR PLANE |
| 5 | COMPLEX CYLINDER |
| 6 | SIMPLE CYLINDER |
| 7 | SPHERE |
| 8 | WELL or MARINELI BEAKER |
| 9 | PIPE |

Figure 3: Selecting the Geometry Template to be used.

Selecting the Template

The next step is to select the source geometry template to be used, which is done from the menu shown in Figure 3. This menu will contain all of the standard templates that are included with ISOCS as well as any custom templates that may have been purchased.

| Parameters Input | |
|--------------------------|--|
| Source Dimensions | |
| Collimator Dimensions | |
| Dimension Units | |
| Air Parameters | |
| Library Material Edition | |
| Current Template View | |

Figure 4: The various types of parameters that can be tailored to each calibration.

Parameter Input

The Parameter Input menu shown in Figure 4 is used to select the type of data to be entered. Note the last item, labeled Current Template View. Selecting it will always display a detailed drawing of the current template similar to the one shown in Figure 5, making it easy to see just which parameters are associated with the template being used. Alternately, depressing the F2 key when in the screen to enter the parameters displays the same drawing.

SIMPLE CYLINDER

Reference Plane = tangent to cylinder outside. Line 6.1 goes thru source reference point (R) and cylinder axis

R = Source Reference Point (center of line where plane contacts cylinder)

D = Detector Reference Point (center of detector)

A = Detector Aiming Point (anywhere on reference plane)

GEOMETRY PARAMETERS

Rename (5):

Geometry Desc. (16):

Comments (50):

Detector Used:

Collimator Used:

☐ Special Collimator Used

Description:

Comments:

1: 2: 3: 4: 5: 6:

7: 8: 9: Mat: Dens:

| REM NO. | DESCRIPTION | a1 | a2 | a3 | a4 | a5 | MATERIAL IDENTIFIER | DENSITY | SOURCE CONCENTRATION |
|---------|-----------------------|----|----|----|----|----|---------------------|---------|----------------------|
| 1 | Container | | | | | | | | |
| 2 | Source - Top layer | | | | | | | | |
| 3 | Source - Bottom layer | | | | | | | | |
| 4 | Absorber 1 | | | | | | | | |
| 5 | Absorber 2 | | | | | | | | |
| 6 | Source Detector | | | | | | | | |

Figure 5: The Simple Cylinder Geometry Definition.

| Parameter Input | | | | |
|-----------------------|---------|------------|-------|----|
| Source Dimensions | | | | |
| Collimator Dimensions | | | | |
| Dimension Units | | | | |
| LENGTH | | | | |
| mm | cm | m | in | ft |
| TEMPERATURE | | | | |
| Celsius | | Fahrenheit | | |
| DENSITY | | | | |
| g/cu.c | kg/cu.m | lb/cu.ft | | |
| AIR PRESSURE | | | | |
| mm.Hg | Bar | kPa | in.Hg | |

Figure 6: Selecting the units for the physical measurement inputs.

Entering the Parameters

Selecting an item in the Parameter Input Menu will pop up a dialog box for use in entering the specified data.

In Figure 7, Dimension Units has been selected. The units to be used for length (sample dimensions), air temperature, sample density, and barometric pressure are selected here.

Figure 9 shows the data entry screen for the source dimensions as well as the source-detector dimensions. Note that the title for the dialog box always identifies the currently selected template, and the contents of the dialog are always tailored to that template.

During the entry of source parameters, the material must be specified. The software performs absorption corrections for each of the object elements. The ISOCS software has a library of materials that can be selected, as shown in Figure 8. And, the user can easily add more materials, as necessary.

Selecting the Collimator Dimensions entry pops up the screen shown in Figure 9. The parameters are as shown in Figure 10.

To simplify the operation of the software, only a few of the parameters are mandatory; the others are needed only if you wish to have them used in the calculations. For example, the size of the sample is mandatory, but things like the size and type of any absorbers that may be located between the detector and the sample are only required when

| Description | d.1 | d.2 | d.3 | d.4 | d.5 | Material | Density | Attenuation |
|-------------------|-----|-----|-----|-----|-----|----------|---------|-------------|
| 1 Container | 0.4 | 0.5 | 0.5 | | | Fe | 7.87 | |
| 2 Top Layer | | | | | | | | |
| 3 Bottom Layer | | | | | | | | |
| 4 Absorber 1 | | | | | | | | |
| 5 Absorber 2 | | | | | | | | |
| 6 Source-Detector | 1.0 | | | | | | | |

Figure 7: The Sample Parameter Input dialog.

| USE (FIND) OR (ADD) MATERIAL NAME TO SEARCH NAME WHEN ENTERED TO RECEIVE | | | | | | | |
|--|---------|----------|----------|----------|----------|----------|----------|
| WATER | AIR | PLXGLASS | CAO | MGO | ALOXIDE | PEOXIDE | FEDOXIDE |
| KOXIDE | NaOXIDE | CACARBON | MGCARBON | CASULFAT | SACID | IRON | SIOXIDE |
| MGOXIDE | TIOXIDE | DRYDIRT | 10WETDRT | 20WETDRT | 30WETDRT | 15WETDRT | |

THE MATERIAL 'WATER' HAS THE FOLLOWING CONTENT:
12.0

Figure 8: The ISOCS Materials Library Screen.

| Collimator | | | | | | | | | |
|---|-----|-----|-----|-----|-----|-----|-----|-----|---------------|
| Description: 1000 Series Collimator with 98 degree collimator | | | | | | | | | |
| Comment: Detector at 5cm from end | | | | | | | | | |
| d.1 | d.2 | d.3 | d.4 | d.5 | d.6 | d.7 | d.8 | d.9 | Material Name |
| 0.5 | 5 | 2.5 | 5 | 2.5 | 5 | 15 | 5 | 2 | Fe 11.35 |

Figure 9: The Collimator Parameters Input Dialog.

you wish to have them taken into account during the calibration process.

The Results

After entering the parameters and performing the calibration, the results—shown in Figure 1—can be stored, retrieved, and used for sample assay in exactly the same manner as those produced by traditional “calibrated source” calibration.

Using ISOCS to Determine the Error Limits of an Assay

Another major benefit of the ISOCS Calibration is the ability to easily determine the error limits of the results of an *in situ* assay.

“What if...?” Errors

This classification covers questions such as “What if the container walls are thicker than we think?”, “What if the container level is not as high as we think?”, and “What if the material matrix is different than we assumed?”

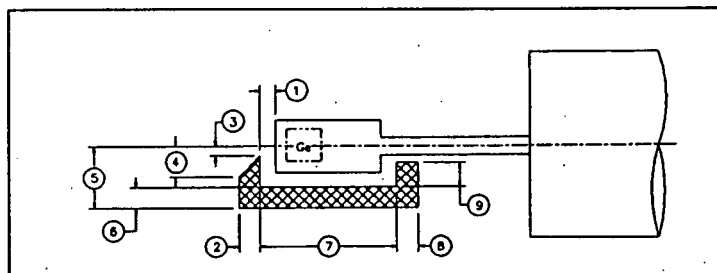


Figure 10: All templates can include a collimator to reduce the field of view or minimize interfering radiation.

To test the impact of these types of assumptions on the results, all that must be done is:

1. Change the value of the parameter to be tested, such as Dimension 1.1 (container wall thickness) in Figures 5 and 7.
2. Have a new efficiency curve generated.
3. Re-analyze the sample spectrum using this new curve.

In a matter of a few seconds you'll see exactly what impact the new assumptions will have on the assay.

Non-homogeneity Errors

This class of error is essentially the same as a sampling error in a traditional "take some random samples and send them to a lab for analysis" method of doing waste assay. That is, if the activity in a container is not homogeneously distributed, how do you know that the assay of your samples (or the results a single ISOCS measurement) truly represent the contents of the container?

For the "sample and analyze" scenario, the only way to find out is to take a very large number of samples, and analyze the distribution.

Even then, the sampling results may not be correct for very non-uniform cases. If the sampling processes happened to completely miss a "hot spot", there is no evidence of the error, nor any measure of the bounds of the error. With *in situ* Gamma Spectroscopy, none of the sample is missed, but some of it may have a different efficiency.

With the ISOCS Ge/Shield/Software System, just perform a few more sample counts with the detector positioned at different locations about the sample. Analyze against the best assumption of the sample definition. Examine the results. For nuclides with multiple energy lines, if all show the same activity, then most likely the calibration is good. If all of the nuclide results from the various source-detector geometries agree, then most likely the calibration is good.

On the other hand, if the results are not the same, just modify the parameters in the source geometry template and reanalyze. This won't take long, and the existing acquisition spectra can be used. This can all be done on site, with none of the turn-around delays inherent in the "sample and analyze" approach.

Typical Results

Extensive testing and validation has been done on both the MCNP Detector Characterization and the ISOCS Calibration algorithms. The full MCNP method has been shown to be accurate to within 5% typically, and 10% for

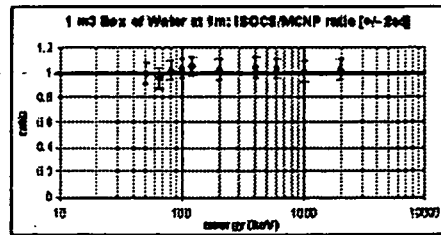
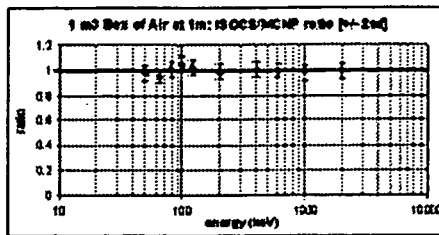


Figure 11: Extensive testing has shown that ISOCS and traditional calibrations typically agree within a few percent.

complex sources and/or low energies. ISOCS results have been compared to a both full MCNP and to calibration sources. In general, ISOCS is accurate to within 10% (15% for <150 keV). A few of the comparisons are shown in Figure 11.

Additional Information

Additional information on ISOCS, its hardware and software components, and its applications may be found in the following publications, all of which are available from Canberra:

Specification Sheets

- Model ISOXSHLD ISOCS Shield System
- Model 1200 InSpector Portable Spectroscopy Workstation
- Model S400/S402/S404 Genie-PC Basic Spectroscopy Software
- Model S401 Genie-PC Gamma Analysis Software
- Model S403 PROcount-PC Counting Procedure Software

Application Notes

- *In Situ Gamma Spectroscopy with ISOCS, an In Situ Object Counting System*, Canberra Industries, Inc.

Publications

- *Validation of the MCNP Monte Carlo Code for Germanium Detector Efficiency Calibrations*, Bronson, Frazier and Wang, Ling, Canberra Industries, Inc., Waste Management '96.

- *Nuclear Instrumentation Tools for Lower Cost and Higher Reliability Decommissioning of Buildings and Grounds*, Bronson, Frazier, Canberra Industries, Inc., TOPSEAL '96.

System Requirements

To use the ISOCS Calibration Software, the following minimum system-configuration is required:

Detector

Any Germanium detector that has been fully characterized by Canberra for ISOCS applications.

Shield

Canberra Model ISOXSHLD ISOCS Shield, or equivalent, if applicable.

Spectroscopy System

Any Canberra PC based MCA system running the following software:

- Canberra Genie-PC Basic Spectroscopy Software.
- Model S401C Genie-PC Gamma Analysis Software.

The PC must be fully IBM compatible, have a math co-processor, and should be a 486DX or higher.

Recommended options include:

- Model S403 PROcount-PC Counting Procedure Software.
- Model S405C Genie-PC Quality Assurance Software.
- Model S406C Genie-PC Interactive Peak Fit Software

Model ISOXSHLD ISOCS Shield Systems

Features

- Portable Germanium detector shield system for *in situ* assays
- Includes 25 mm and 50 mm thick lead shields
- Reduces interfering 1000 keV radiation a factor of 7.5 (25 mm) and 60 (50 mm)
- Modular design for easy handling
- Stainless steel construction or epoxy paint for ease of cleaning
- Includes 30° and 90° collimators (each thickness) plus solid end caps for background measurements
- Includes a rear shield plug (requires RDC option on detector)
- Wheeled mounting stand for ease in moving the shield from one sample to the next
- Upper and lower detector mounting positions, with 180° detector rotation at either location
- Easy to assemble and to change detector positions
- Built-in laser aiming device
- Components from 25 mm and 50 mm shields may be combined to build a sample counting chamber

Description

This ISOCS (*In Situ* Object Counting System) Shield (Figure 1) has been designed as the optimum in convenience and functionality for *in situ* gamma spectroscopy with a Germanium detector. The system is supplied with both 25 mm and 50 mm lead shielding which gives you the ability to utilize the sensitivity and low background capabilities of a laboratory grade Germanium spectrometer directly on site, regardless of where that site is located.

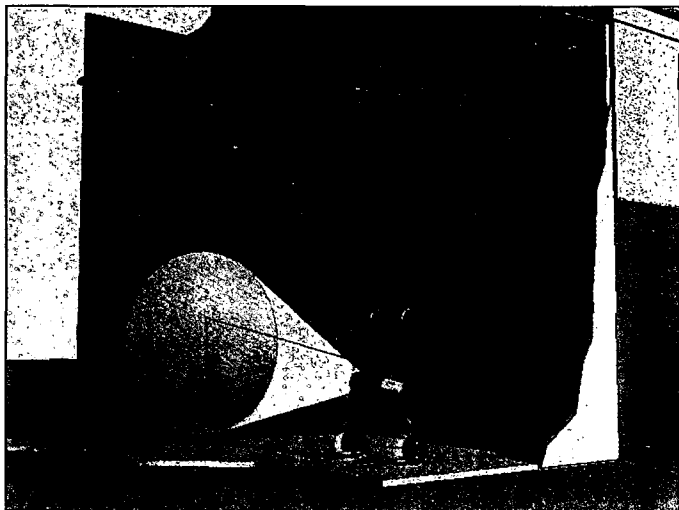


Figure 2
Using the ISOCS Shield System to assay a wall.

Unshielded, the detector has a nearly 360° field of view, and can be used for 4 π counting of the walls/floors/contents of an entire room. The field of view can be reduced (Figure 2) by adding the shield and collimators to provide fields of view of 30°, 90°, and nearly 180° by simply sliding the appropriate shield components on the mounting

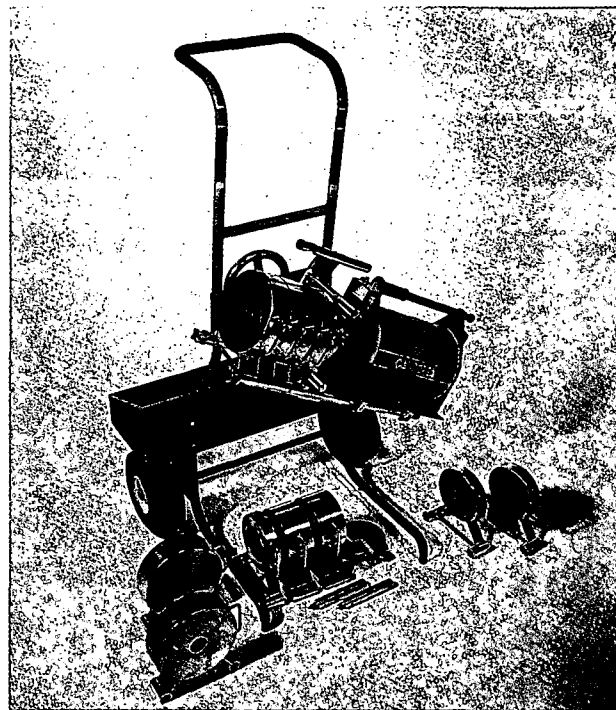


Figure 1
The ISOCS Shield Systems and all of their available components installed on an RDC Ge Detector with a Big MAC Dewar. (See Figure 3 for current design.)

rails. In addition, a completely shielded sample chamber can be assembled by combining the components from the two systems.

Its standard wheeled mounting stand makes it easy to move the shield at the assay site.

The mounting stand features both an upper (for 1-meter detector/ground counting) and lower (normal) detector mounting location, plus allows 180° detector rotation at either location, for maximum positioning flexibility. The detector holder even includes a laser pointer to aid in aiming the detector at remote objects.

Whatever the sample and wherever it's located, the ISOCS Shield System has the versatility and flexibility to count it.

THE DETECTOR

A major benefit of the ISOCS Shield System is the ability to use most any type or size of detector for the intended application required. While the most typical would be a coaxial Germanium with a 40-60% relative efficiency, the shield can easily accommodate detectors as large as 100-120% relative efficiency.

A wide variety of detector types are also supported, including Reverse Electrode (REGe), Low Energy (LEGe), and Extended Range (XtRa) Germanium, giving you the flexibility to match the detector's response to the types of samples that are anticipated.

To take the maximum advantage of the ISOCS shield, the detector of choice should be mounted in a Remote Detector Chamber (RDC)

cryostat. This allows the shield's rear end plate to be used, minimizing any interfering radiation that may enter the rear of the detector.

Whichever type and size of detector is chosen, its energy response must be fully characterized by Canberra if it is to be used with the Model ISOXSW ISOCS Calibration Software as part of a complete *in situ* assay system.

THE CRYOSTAT

The ISOCS Shield System is designed to accommodate either Canberra's MAC (Multi-attitude Cryostat) or Big MAC. The MAC provides two days LN₂ holding time and may be operated in any orientation with no LN₂ spillage or reduction in capacity. It also can fit within the optional 702 shipping case, along with the PC and InSpector MCA. Alternatively, the Big MAC with a five day holding time may be used if LN₂ filling is inconvenient.

THE STAND

The ISOCS Shield System (Figures 1 and 3) includes a wheeled stand that is used both for transporting the system about a site and for sample assay. The stand features upper (for 1-meter downward looking orientation) and lower (for side-upward looking) mounting positions for the detector and shield. In either of the two positions, the detector may be freely rotated about its mounting axis, providing maximum flexibility in detector positioning. No tools are required for detector rotation or shield assembly.

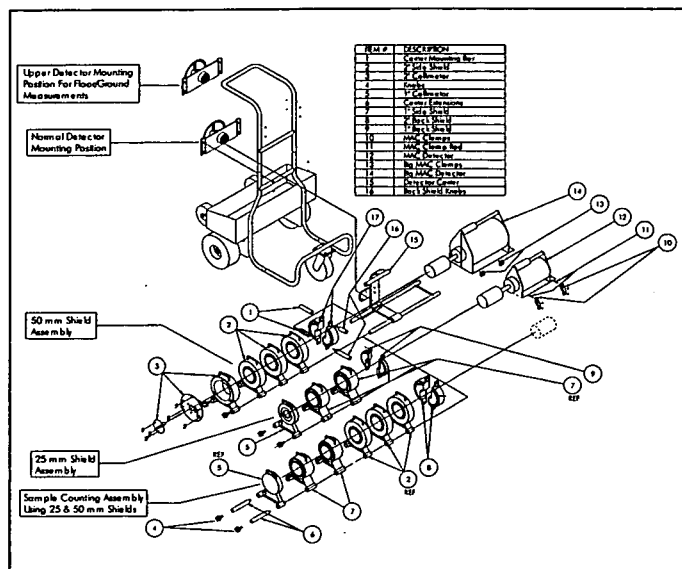


Figure 3

The components of the complete ISOCS Shield System.

To aid in positioning the detector, particularly when assaying a remote object like an overhead coolant pipe (See Figure 4), a battery operated low power laser aiming device is built into the shield's mounting assembly handle.

THE SHIELDS AND COLLIMATORS

The two shield assemblies supplied with the ISOCS Shield System are essentially identical except for the thickness of the lead, 25 mm (1 in.) and 50 mm (2 in.), from which they are made. The components of the complete shield system, together with a detector in an RDC cryostat attached to a Big MAC Dewar, can be seen in Figure 3.



4a: Assaying tanks or drums.



4b: Assaying pipes.



4c: Traditional soil and floor assay.

Figure 4

The flexible ISOCS Shield System adapts to most any *in situ* counting geometry.

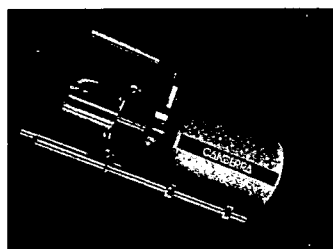
Each shield consists of the following modules:

BACKSHIELD SECTIONS – These two elements connect together and shield the rear of a detector mounted in an RDC cryostat. Its location is behind the detector chamber (Figures 5a and 5b).

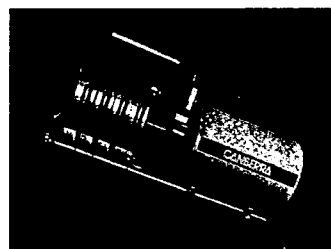
MAIN BODY MODULES – These make up the walls of the shield. There are two with the 25 mm shield; and three with the 50 mm shield. When counting Marinelli beakers, only 1 module is used (Figure 6a).

COLLIMATORS – Includes collimators for 30° and 90° fields of view. With none installed, the field of view is nearly 180°.

TOP PLATE – The Top Plate is used for performing background runs and for use as a chamber closure when counting packaged samples (See Figure 6b).



5a: The detector and mounting assembly. Note the RDC detector chamber.



5b: The same detector with the 50 mm Shield and a Collimator installed.

Figure 5

Details of the ISOCS Shield and Mounting System.

Each module is manufactured from low background lead, and has a stainless steel outer shell and a durable epoxy covering for easy cleaning and decontamination.

Figures 8 and 9 show the radiation attenuation and background reduction of the various shields and collimators.

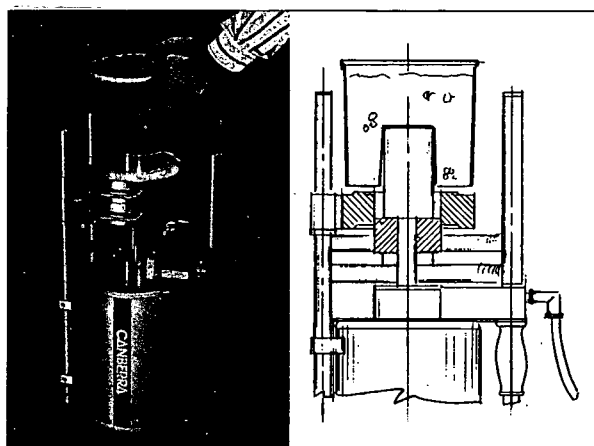
All of the sections are designed to slip onto the system's mounting rails, as shown in Figures 3 and 5, without the use of tools.

While the shields are normally used individually, the modules from the two may be easily combined to form a shielded sample chamber, as shown in Figure 6b. The 50 mm modules shield the detector, with the

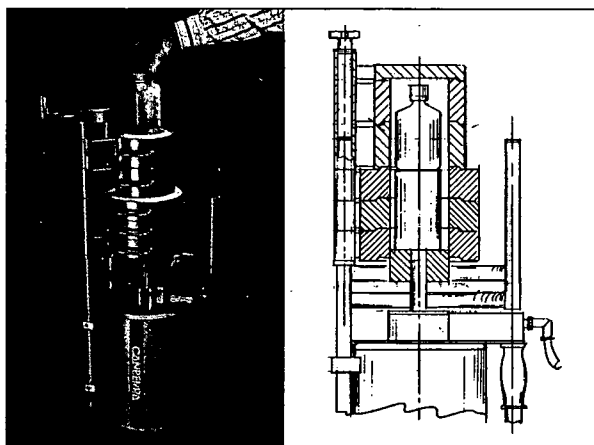
25 mm modules forming the sample chamber. The sample size can be up to 10 cm diameter by 15 cm in height.

For assaying samples in Marinelli beakers, the configuration shown in Figure 6a is used. Note that this arrangement can be constructed from either the 25 mm or 50 mm shields.

For most every sample encountered in most any environment, the ISOCS Shield System provides the flexibility and performance for fast, accurate assays.



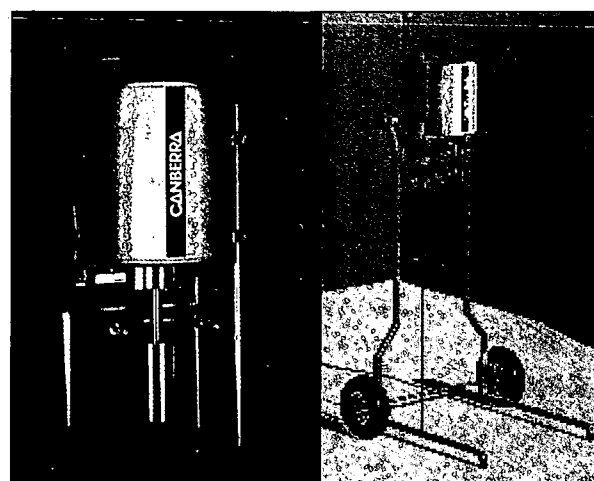
6a: Configured for a Marinelli beaker.



6b: Configured for a traditional sample.

Figure 6

The ISOCS Detector and Shield can be configured for counting both Marinelli beakers and traditionally packaged samples.



7a: Unshielded and uncollimated.



7b: Shield and Collimator installed.

Figure 7

When counting soil or floors, the ISOCS can be used uncollimated for maximum sensitivity, or collimated to reduce background and field of view.

Specifications

DETECTOR REQUIREMENTS

TYPE - Any type of Canberra Germanium detector with an end cap diameter of less than 10 cm (4 in.).

CRYOSTAT - Greatest background reduction will be attained with the RDC cryostat option.

DEWAR - Either a MAC or Big MAC may be used.

STAND AND DETECTOR/SHIELD HOLDER

CONSTRUCTION - Stainless Steel (detector holder), epoxy painted carbon steel (stand). Includes shield carrying tray. The handle, legs, tray, and wheels are easily removed for access to small areas, or shipping.

SHIELDS

MATERIAL - 25 mm (1 in.) and 50 mm (2 in.) lead.

FINISH - Steel exterior and epoxy paint on exposed lead.

BODY MODULES - Includes two 25 mm and three 50 mm modules.

COLLIMATORS - Includes 30° and 90° collimators. Custom sizes available.

END SHIELDS - Includes solid end shield of each thickness for background measurements.

BACKSHIELDS - Includes a set for each lead thickness.

FULLY ASSEMBLED SYSTEM

SIZE - 132 x 78.7 x 96.5 cm (52 x 31 x 38 in.) fully assembled.

WEIGHT -

STAND/DETECTOR/HOLDER - 77 kg (170 lb).

WITH ALL 25 MM SHIELDS - 101 kg (223 lb).

WITH ALL 50 MM SHIELDS - 133 kg (294 lb).

WITH BOTH SHIELD SETS - 157 kg (347 lb).

HEAVIEST SHIELD MODULE - 16.3 kg (36 lb).

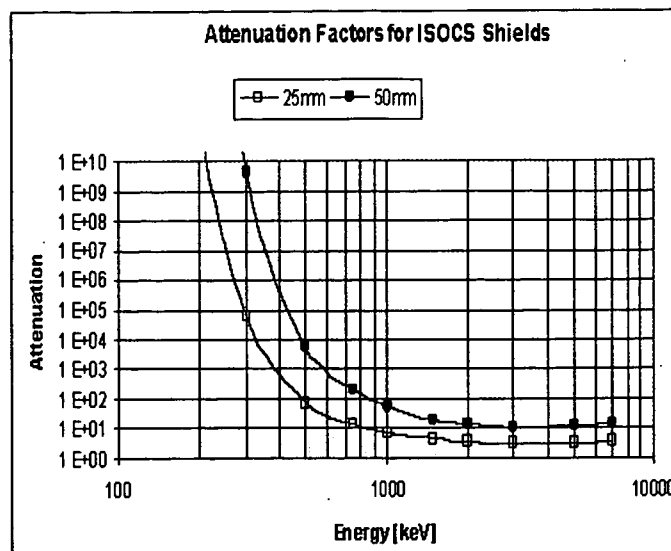


Figure 8
Attenuation vs. Energy for the ISOCS Shields.

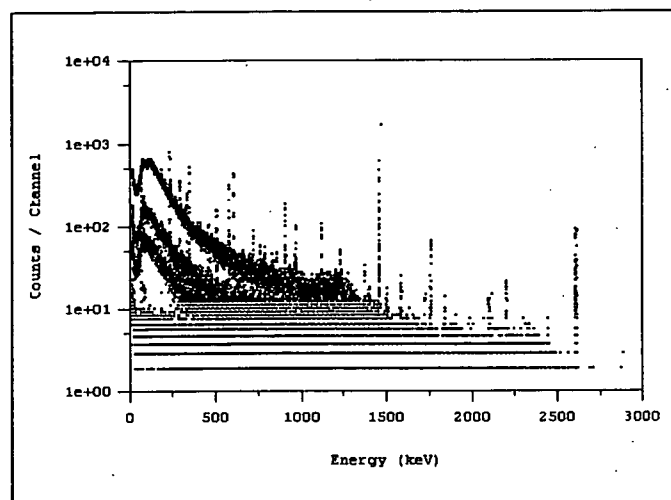
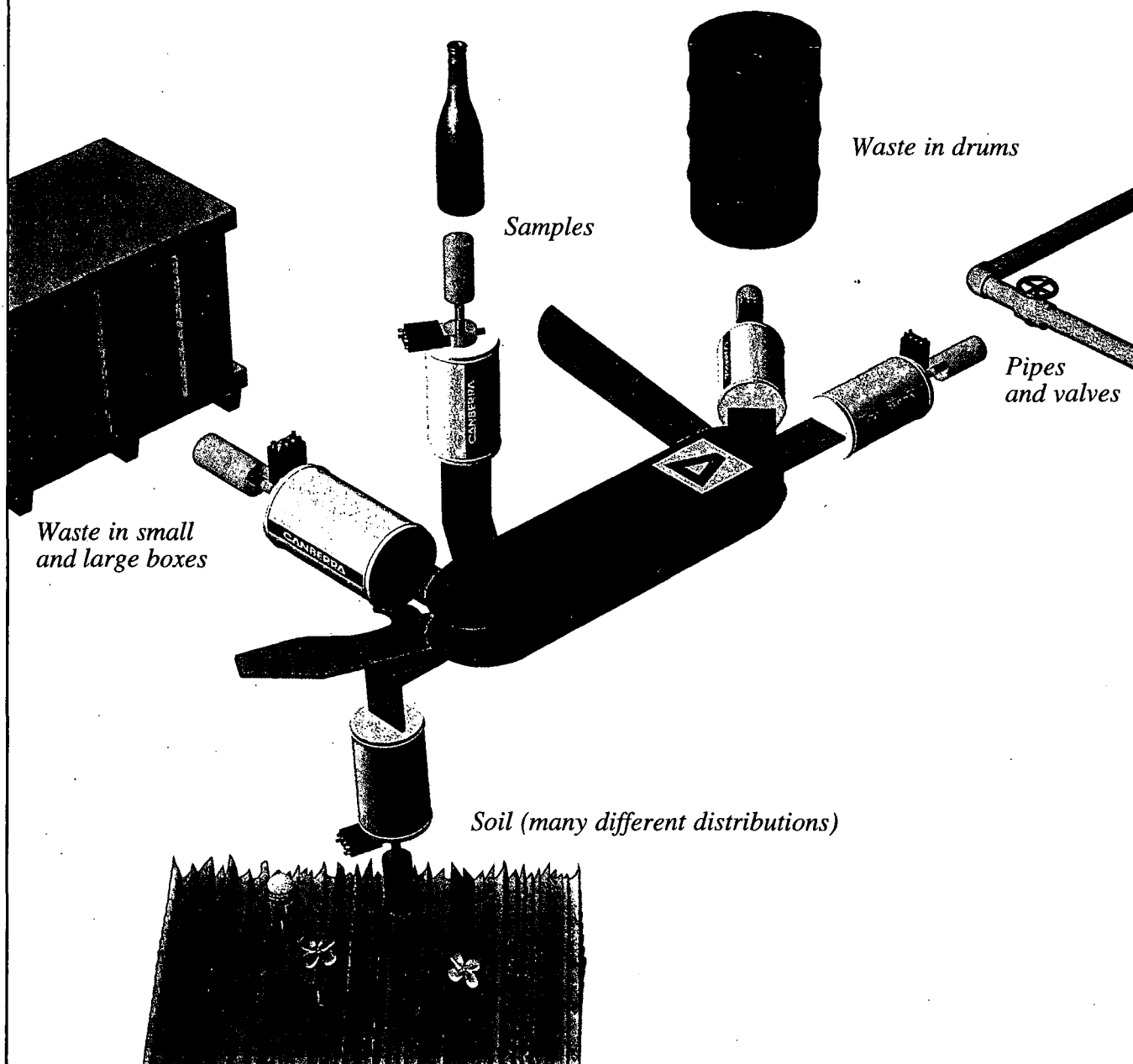


Figure 9
Background Radiation vs. Energy for the ISOCS 50 mm Shields.
Data shown represents unshielded (top), side shield only (middle), 90° collimator and 30° collimator.

ISOCS ... The Versatile Field Gamma Spectroscopy Tool



We have tried to show a few of the many applications of ISOCS that make it as versatile as the proverbial Swiss Army Knife. If you would like a copy of the ISOCS Application Note or if you need additional information, then call/write/fax/e-mail Canberra today.



CANBERRA

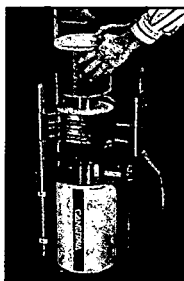
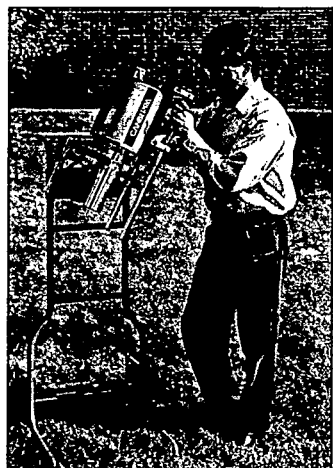
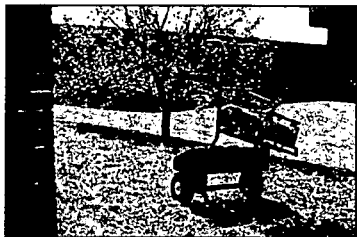
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Now You Can Take The Gamma Spectroscopy Laboratory To The Sample



For Results That Are "Faster/Better/Cheaper", Checkout Canberra's New *In Situ* Object Counting System (ISOCS)...

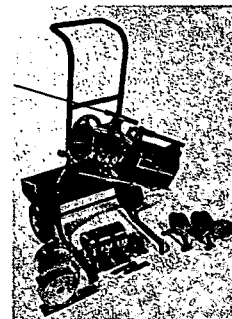
It's a new, innovative portable system that:

- Counts walls, floors, pipes, boxes, drums, soil, wells, trenches, small samples... or most every sample configurations you encounter;
- Has modular lead shielding to reduce interference from other sources;
- Can be moved and used by one technician;
- Gives you the result in minutes so you can use it for your next measurement;
- Tells you which nuclides are present and the amount of radioactivity of each nuclide; and
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VALIDATION OF THE MCNP MONTE CARLO CODE FOR GERMANIUM DETECTOR GAMMA EFFICIENCY CALIBRATIONS

Frazier L. Bronson and Ling Wang
Canberra Industries, 800 Research Parkway, Meriden, CT, USA

ABSTRACT

Canberra designs a variety of instruments that are required to accurately measure the radioactivity content of large and/or complex sources. The Monte Carlo code MCNP was evaluated to determine if it would be suitable to predict the performance of these instruments. A series of experiments was designed, starting with simple source-detector geometries and becoming increasingly more complex. For each geometry the full energy peak efficiency was computed with MCNP, and also measured experimentally. Multiple energies (nominally 100-1500 keV) were used for each experiment. The lessons learned from each experiment are described, and were suitably incorporated into later experiments.

Computer run time can be quite long, and therefore a geometrical biasing scheme was developed to make these computations more practical. The speed advantage can be a factor of 10 or greater.

It is concluded that this technique is very powerful and accurate when properly applied. For the geometries tested, efficiency calibrations are accurately predicted to within 5% for simple geometries, and up to 15% for complex geometries at low energies.

Presented at Waste Management '96

February 28, 1996

Tucson AZ USA

VALIDATION OF THE MCNP MONTE CARLO CODE FOR GERMANIUM DETECTOR GAMMA EFFICIENCY CALIBRATIONS

Frazier L. Bronson and Ling Wang
Canberra Industries, 800 Research Parkway, Meriden, CT, USA

INTRODUCTION

The primary purpose of this project was to develop a design tool for the evaluation of the various detector-geometry factors as we create new radioactive waste assay systems. These gamma spectroscopy systems are required to measure large and often complex samples. The sample sizes range from 200 liters to 36000 liters. It is necessary to create the optimum detector placement strategy in order to achieve the lowest minimum detection limit and to minimize sample non-homogeneity errors. The traditional methods we have employed in the past [1] have used real detectors of varying sizes, and multiple geometries made with radioactive sources. While suitable for simple [cylindrical] and small [200 liter] samples, this becomes less practical as the sample size and complexity increases. And, the use of radioactive samples for testing and calibration generates radioactive waste.

A potentially useful tool would be Monte Carlo modeling. MCNP [2] is a well known general-purpose Monte Carlo code commonly used for neutron transport applications. It is also capable of modeling photon problems. There have been a few very useful publications describing the use of MCNP to model gamma ray spectra and efficiencies for Ge detectors [3,4,5,6]. However, these have generally evaluated fairly simple detector-source geometries, or they have not performed direct efficiency calibrations [6]. Important issues such as what are the critical parameters, how much detail is necessary in the model, etc. have not been studied, or reported.

At a minimum, the goal of this project was to develop a tool useful for relative comparisons. This tool could then be used for selecting the optimum size, number, type, and placement of detectors. We could then also investigate the relative error associated with non-homogeneity of the sample in the matrix. The ultimate goal, however, is to demonstrate that we can accurately model these complex geometries, and then be able to determine system performance prior to building the first system. If we can accomplish this goal, then we can use MCNP to accurately and economically perform the *primary* calibration for a wide variety of sample conditions.

In this report, we present the results of a detailed study showing the validity of the use of MCNP to perform efficiency calculations of complex geometries with Ge detectors.

METHODOLOGY

A sequence of different source-detector geometries was created. Six major geometries with a total of 16 different source-detector geometries were modeled for efficiency determinations. These started with simple geometries, and proceeded to increasingly more complex geometries. The geometry was first modeled and the efficiency computed using MCNP. Then a multi-energy calibration source was used to develop a traditional efficiency calibration for the same geometry.

The test geometries modeled and measured for this study were the following:

1. Full energy peak efficiency for a small multi-energy gamma source positioned at a distance of about 40 cm and at 0, 45, and 90 degrees with respect to the axis of a 32% relative efficiency coaxial Ge detector.
2. Full energy peak efficiency for a Eu-152 multi-energy line source of 80 cm in length, positioned 14 cm from the endcap of a 30% relative efficiency coaxial Ge detector.
3. Full energy peak efficiency for a multi-energy planar gamma source 50 x 50 cm positioned 8 cm from the endcap of a 25% relative efficiency coaxial Ge detector.
4. Full energy peak efficiency for a series of single nuclide sources in a 1 liter water-equivalent matrix in a Marinelli beaker with a 25% relative efficiency coaxial Ge detector.
5. Full energy peak efficiency for a Eu-152 point source successively shielded by 0, 1.0, 3.0, 6.1 and 9.1 cm of steel placed between the source and a 25% relative efficiency coaxial detector.
6. Full energy peak efficiency for a multi-energy simulated volume source in a 200 liter (55 gal) drum at four different drum matrix densities in a Canberra Q² Low Level Waste Assay system with three nominally 28% relative efficiency Ge detectors.

The multi-energy source had nuclides from 88 to 1836 keV. Eu-152 was analyzed for each of the lines to give datapoints from 122 to 1408 keV. The Marinelli beaker sources had energies from 60 to 1115 keV.

Each of the six experiments was performed separately and sequentially. The two efficiencies [modeled and measured] were compared. Where there were differences that were statistically significant and greater than approximately 5%, both the calculation and the source measurement were examined carefully. Generally, this resulted in increasing the complexity of the source and/or detector model, and then the recalculations were in better agreement. But some changes were also made in the setup of MCNP, or to the code to improve performance and/or speed. When each

experiment was at its best agreement, then the next experiment was started. What was learned in earlier experiments was successively applied to later experiments. However, we generally did not go back and try to refine the earlier experiments.

MCNP CONSIDERATIONS

The MCNP input files for all of the above geometries were created by following the standard procedure described in detail in reference [2]. The input files consist of four parts: a geometry part, a source definition part, a material part and a tally part.

Only the photon mode was used. Electron mode was not used because it takes at least 40 times longer than that with photon mode alone. Although electron transport was not simulated, the electron-induced photons were not neglected. A thick-target bremsstrahlung model (TTB) was used instead. The TTB model also generates electrons, but assumes that they travel in the direction of the incident photon and that they are immediately converted. The bremsstrahlung photons produced by these electrons are then banked for later transport.

The detailed physics treatment (default MCNP choice) for photon interactions was chosen for all geometries in this report.

There are many tally types in MCNP. For our application, only tally 8 (pulse height tally) was necessary. For this tally, the only possible variance reduction scheme is biasing of the source itself.

The direction of a gamma photon at birth is determined by an azimuthal angle ($0-2\pi$) and a polar angle (0π). In reality, photons are emitted isotropically over 4π solid angle. When a source is far away from the detector, most of the photons will never reach the detector due to the low geometrical efficiency. Since there is no variance reduction scheme to shorten or terminate the life of those photons for this tally type, there is much wasted calculation time. However, if one is only interested in the total efficiency of a detector, and if in the energy range of interest the elastic (Thomson, or coherent) scattering is not important, then directional biasing schemes can be used. In this method, only a small range of the azimuthal and polar angle is used. Instead of the full 4π solid angle, particles are forced to be emitted from the

source in a direction toward the detector, and with all photons in a cone which entirely encloses the detector volume. Since only a small fraction of the particles are modeled (in most cases less than 10%), this method can greatly reduce the computation time. The results are then corrected by the ratio of the solid angle subtended with the biasing cone to the four total solid angle. This will then yield the same efficiency response as if no biasing was used.

When elastic scattering becomes important (which is more likely at lower energies and in heavily attenuated sources), using highly collimated directional biasing will result in somewhat lower computed "efficiency". If this loss is considered significant, then one must use the full 4π emission angle in order to achieve the desired accuracy.

Unless otherwise stated, directional biasing was the default method used for most of the MCNP efficiency calculations in this report. The few cases where this method did not give accurate results are discussed.

The MCNP output for pulse height tally is in counts (normalized by number of histories at that energy) vs energy. For all the efficiency calculations, the channel width was set to 1 keV. The efficiencies are obtained from output files by subtracting the background continuum counts (the average of the counts in the left and right neighboring energy bins) from the peak counts. This was done with a custom software routine.

All of the experimental results were taken and analyzed by standard Canberra instruments and software. Because these tests covered over a year in time, various detectors, MCAs, and data analysis software were used. All MCAs were properly calibrated for energy, and had adequate gain to sufficiently resolve the peaks of interest. Although the spectra were analyzed using various Canberra software packages, all of the analysis algorithms used compute the full energy background-corrected net peak count rate for each of the relevant peaks of the spectra in a similar manner. Therefore, the results are comparable.

In almost all of the MCNP calculations for full energy peak efficiency, the statistical precision of MCNP calculations and experimental measurements was kept less than 3% to ensure the statistical validity of the results.

Three kinds of computers were used for the MCNP calculations: DEC Alpha AXP (DEC chip 21064), VAX 4000 and IBM PS/ValuePoint (Intel 486DX2-66Hz). The ratio of the speed for these machines is roughly 6:1:1 (AXP:VAX:IBM).

RESULTS AND DISCUSSION

Each of the experiments described in this section has an introductory text description, a simple graphical portrayal of the detector geometry, and a graphical presentation of the energy/efficiency comparison, and a discussion of the results.

Unless otherwise mentioned, the total number of particles are equal for each energy (equal weights are given for each energy). However, more CPU time is spent on the higher energy photons because the lifetime of higher energy photons is usually longer than that of lower energy photons in the simulation.

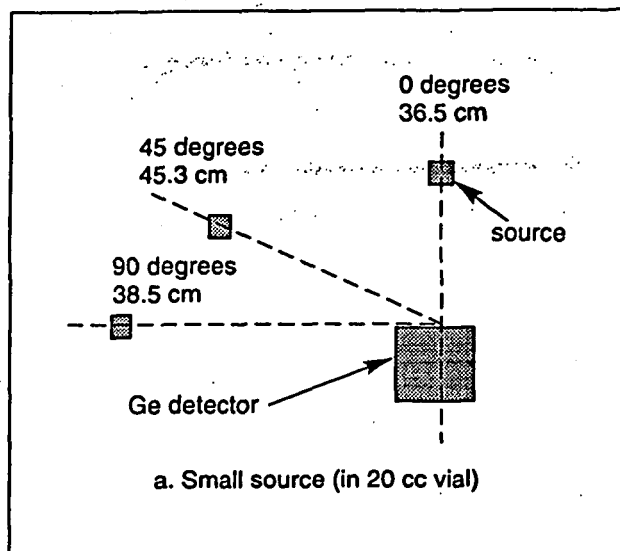
Test 1: Multi-energy small source at various angles

The detector used was a Canberra P-type coaxial Ge detector (S/N 3155). The detector had 32% relative efficiency at 1332 keV. The detector physical size is 53.4 mm diameter and 62.0 mm length. Other physical features of the detector (e.g. top and side dead layer thickness, detector holder, detector well and groove, detector holder and all endcap features) are included into the model. The source used in the experiment was a mixed gamma source in a 20 cc cylindrical liquid scintillation counting vial from Analytics, Inc. (S/N 46481-121). It contained nuclides with 10 energies from 88 keV to 1836 keV. Three cases were studied:

- source on axis at a distance 36.5 cm from the detector endcap;
- source 45 degrees at 48.3 cm;
- source 90 degrees at 38.5 cm.

The geometry and graphical presentation of the results are shown in Figure 1. The agreement between MCNP and experimental measurements is excellent. For the 0 degree angle source position, the largest relative difference is 5% for all energies, and the overall average difference is 3%. This geometry is straightforward to model since the shape of the materials, such as the Al endcap and detector dead layer between the source and the detector, is cylindrical.

For 45 degrees, the largest relative difference is 6% for all the energies and the overall average difference is 2%. For 90 degrees, the largest relative difference is just slightly higher at 7%, and the overall average difference becomes 4%. For the off-axis geometries, we found it necessary to add many more features to the detector model (holder, endcap, side dead layer, etc.) in order to achieve the results shown.



Test 2: Eu-152 line source

Although in the previous geometry both the source volume and density were included in the model, the distance effect makes it more or less like a point source. The objective of this geometry is to see how accurate MCNP is when the source is extended linearly.

The detector used was a Canberra P-type coaxial Ge detector (S/N 3202). The detector had 30% relative efficiency at 1332 keV. The detector physical size is 53.0 mm diameter and 59.5 mm length. The source used in the experiment is a Eu-152 line source from North American Scientific, Inc. (S/N A0980). The activity of the source was uniformly distributed in an epoxy matrix with a density of 1.07 g/cc and cast in 6.53 mm O.D. Tygon tubing. This tubing is then inserted into rigid plastic tubing with an overall length of 80 mm and an outer diameter of 10.3 mm. The source was placed horizontally, 14 cm above the detector Al endcap and supported by a plastic disk. The detector axis passes through the center of the line source. All of these factors were included in the model.

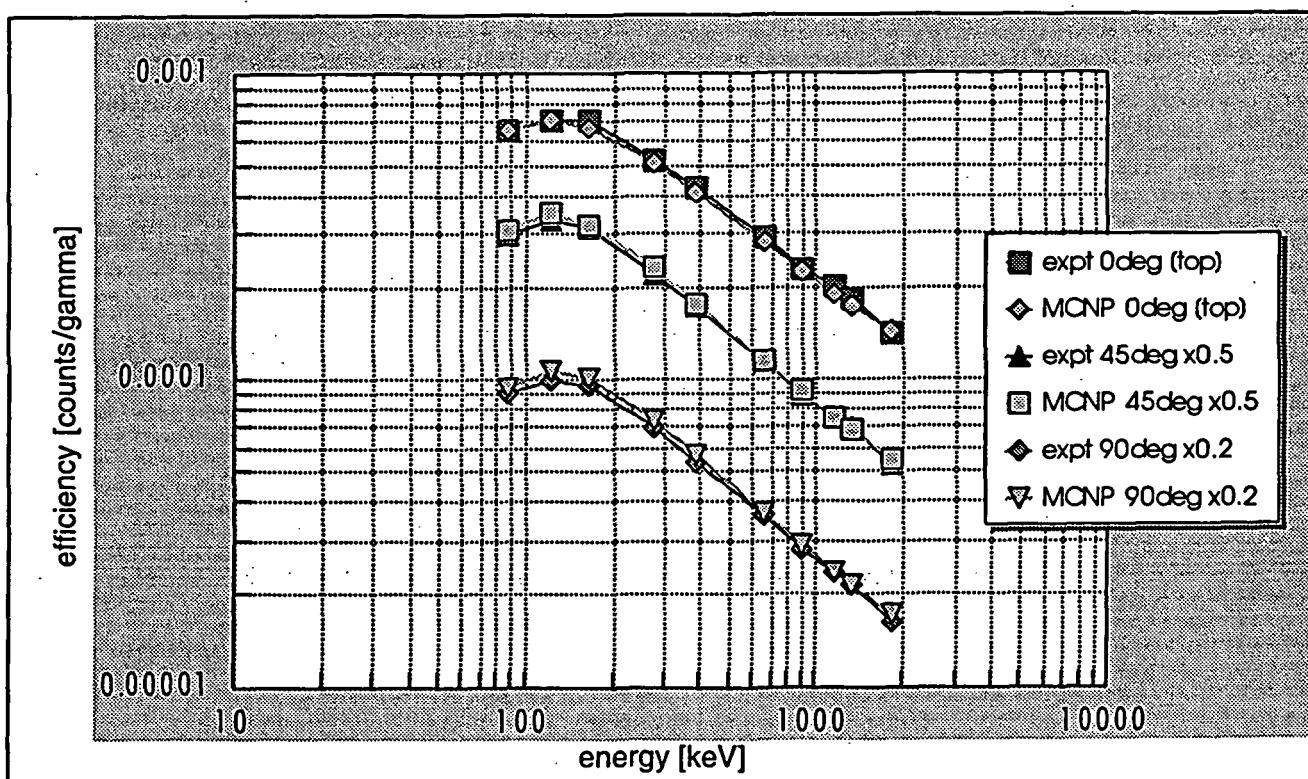


Figure 1: Multi-energy small source at various angles.

The initial results indicated an average 17% bias between the experimental data and the calculated results. Additional features to the model, and repeated measurements of the line source did not change the bias. Other detectors were used for both MCNP and experimental measurements and gave the same bias. But a summation of point source measurements done to simulate the line source had quite good agreement with the MCNP data. This led us to suspect the

calibration source accuracy. This was later confirmed by the manufacturer with an amended calibration certificate.

The test geometry is shown in Figure 2(a) and the final results are shown in the graph of Figure 2, middle data set. The agreement is excellent at all energies, with largest relative difference of 3% and overall relative difference of 2%.

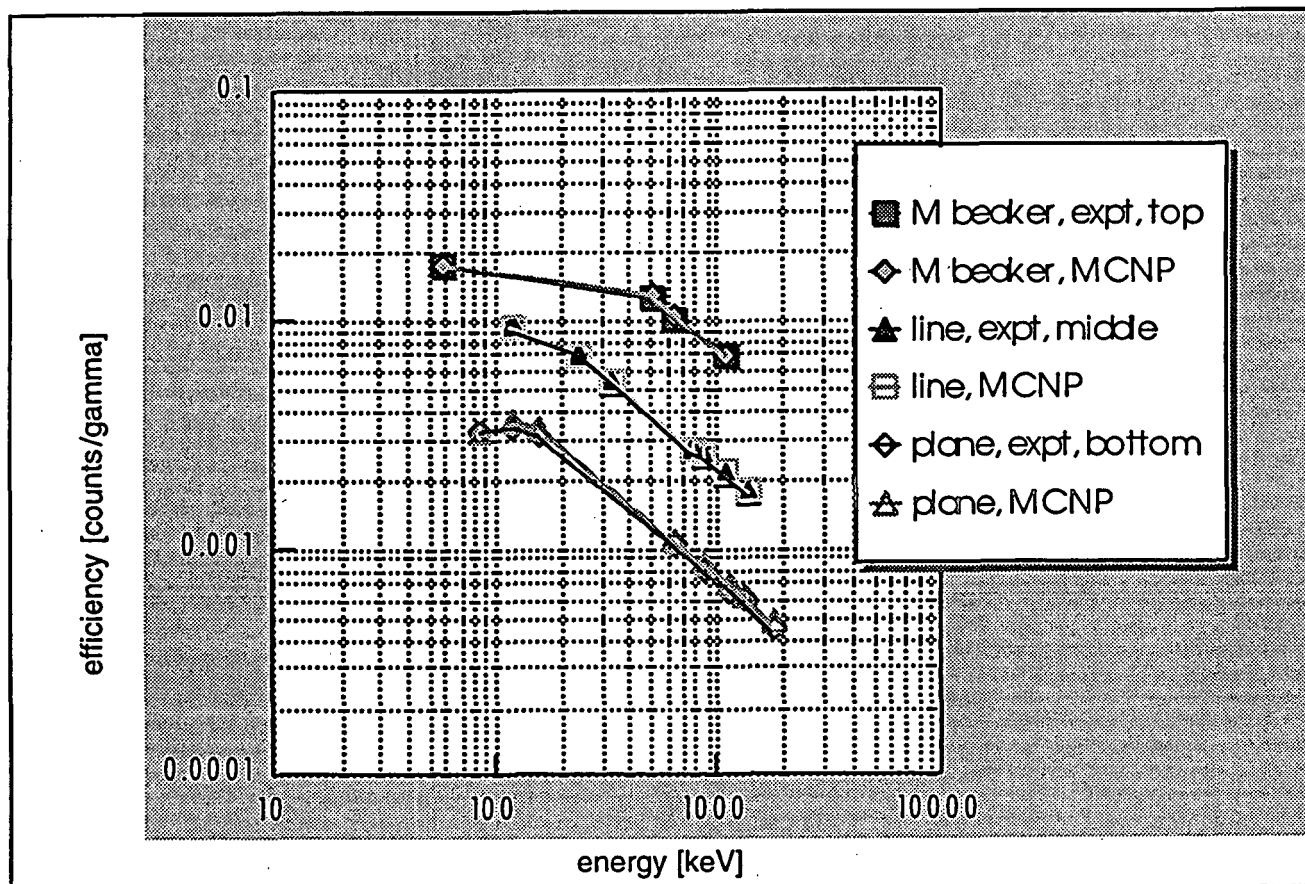
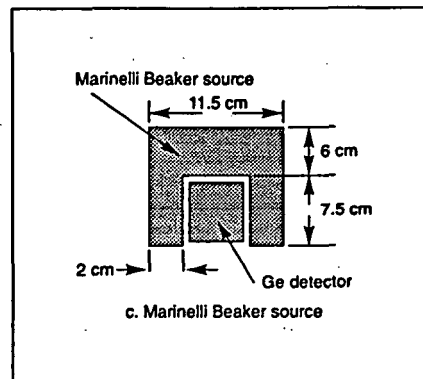
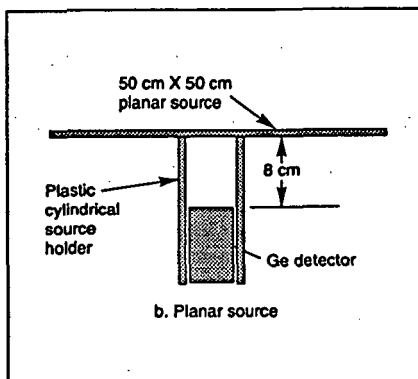
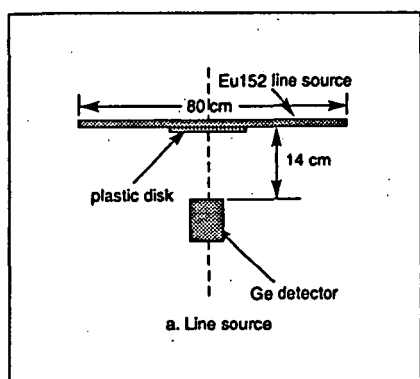


Figure 2. Tests 2 [line], 3 [plane], and 4 [Marinelli Beaker].

Test 3: Mixed gamma plane source

This experiment is intended to extend the calibration validation from a one dimensional source to two-dimensional planar large area source.

The detector used was a Canberra P-type coaxial Ge detector (S/N 3313). The detector had 25% relative efficiency at 1332 keV. The detector physical size is 52.0 mm diameter and 53.0 mm length.

The source used was manufactured by North American Scientific, Inc. It is a thin (1 mm) source with an area of 50 x 50 cm, backed by a support plate for a total thickness of 1 cm. It was placed 8 cm above the Al endcap of the detector. The source is supported by a 10.2 cm I.D. 0.64 cm thick plastic pipe. All of these geometrical factors were included in the model.

The test geometry is shown in Figure 2(b), with the graphical results in Figure 2, bottom data set. The largest relative difference is 10%, and the overall difference is 6%. There is a positive bias of approximately 7% in the MCNP efficiency over the source efficiency. It is unclear what is causing this bias. The two likely possibilities are that the source has a non-uniform distribution in the source plane, or that the source activity is different than on the source document, as in the line source case. However, by the time this was identified, the source was no longer available for re-calibration to verify these hypotheses.

Test 4: Marinelli beaker source

This common geometry is an additional extrapolation of the extended plane source in Experiment 3, but with a moderately thick sample.

The detector used was a Canberra P-type coaxial Ge detector (S/N 3313). The detector had 25% relative efficiency at 1332 keV. The detector physical size is 52.0 mm diameter and 53.0 mm length. Three Marinelli beaker sources made by Analytics, Inc. were used (Cs-137 for 662 keV, Am-241 for 60 keV, and Zn-65 for 511 and 1115 keV). These sources are specifically chosen to eliminate coincident summing effects in the experimental data for this high efficiency geometry. The source volumes are all 1 liter with matrix density of 1.09 g/cc. The source sits right on top of the detector. No directional biasing was used because this is a relatively high efficiency geometry.

The test geometry is shown in Figure 2(c) and the results are in the graph of Figure 2, top data set. The agreement between MCNP and experiment is excellent. All the relative differences are within the statistical uncertainty given by the source and MCNP calculation. The largest relative difference is 4% and the overall difference is 2%, with an uncertainty of 2.5%.

Test 5: Heavily shielded mixed gamma source

The objective of this test is to evaluate the ability of MCNP and properly calculate the effect of heavily attenuated sources. This is also important for successful calibrations of very thick sources.

The detector used was a Canberra P-type coaxial Ge detector (S/N 3313). The detector had 25% relative efficiency at 1332 keV. The detector physical size is 52.0 mm diameter and 53.0 mm length. The source was made by North American Scientific, Inc. The activity of the source is contained on a 1 mm diameter resin bead in the center of a 2.5 cm diameter by 0.64 cm thick plastic disc. Attenuators made of steel disks with thickness' of 0.0, 1.0, 3.0, 6.1 and 9.1 cm were placed between the source and the detector. The steel shield disks have a radius of 10 cm. The shield is supported by a 10.2 cm I.D. 0.64 cm thick plastic pipe and a Eu-152 button source was placed right on top of the shield. All of these are included in the model.

The test geometry and the graphical results are shown in Figure 3. The low energy data points are missing in the 6.1 and 9.1 cm cases because the corresponding experimental and MCNP lines are almost completely shielded. For 0 cm thickness, the agreement between experimental and MCNP results is excellent with the largest difference of 3%. Even at the maximum thickness where there is 99.9% attenuation, the agreement is still very good (within 6%) and all data are individually statistically acceptable.

Test 6: Multiple line sources in a 55 gallon drum in a Canberra Q² system with three detectors

This experiment was designed to demonstrate the capabilities of MCNP to accurately model very complex sources.

The Q² counter is a standard nuclear waste assay system designed and manufactured by Canberra. It is shown schematically in Figure 4(a). The typical size of the steel shield is nominally 100 x 100 x 100 cm with a wall thickness of 16 cm. A 200 liter drum which contains the sample to be assayed sits on a rotating table. The standard system is equipped with three vertically aligned Ge detectors viewing the sample radially through holes in one of the shield walls. The drum is rotated about the axis multiple times during the measurement.

The Ge detectors used are Canberra standard coaxial (S/N 3292, 3277 and 3290) with similar sizes (50 mm O.D. and 45 mm length) and similar performance (28% relative efficiency at 1332 keV).

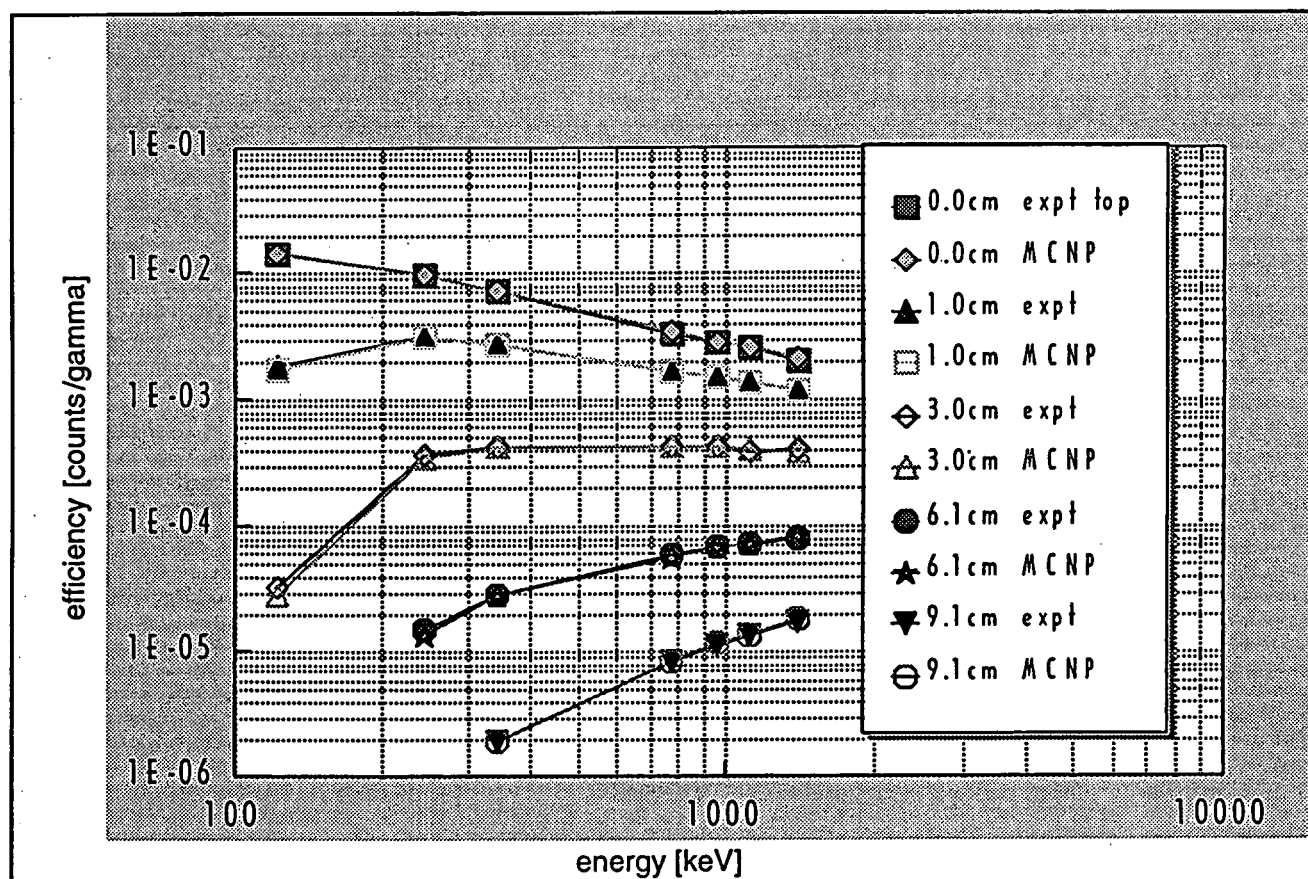
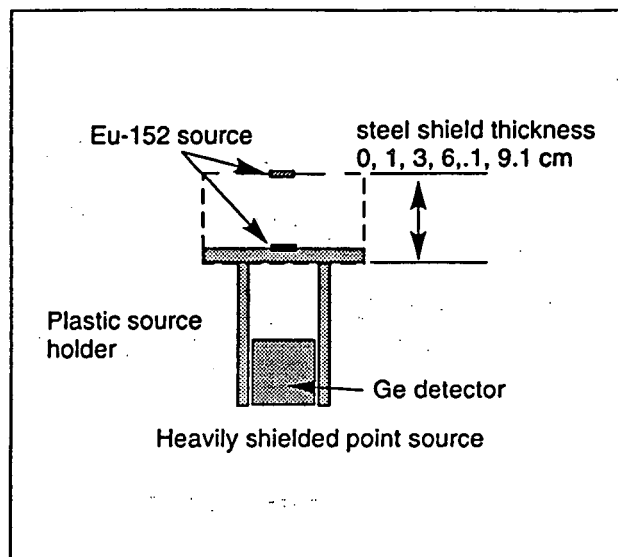
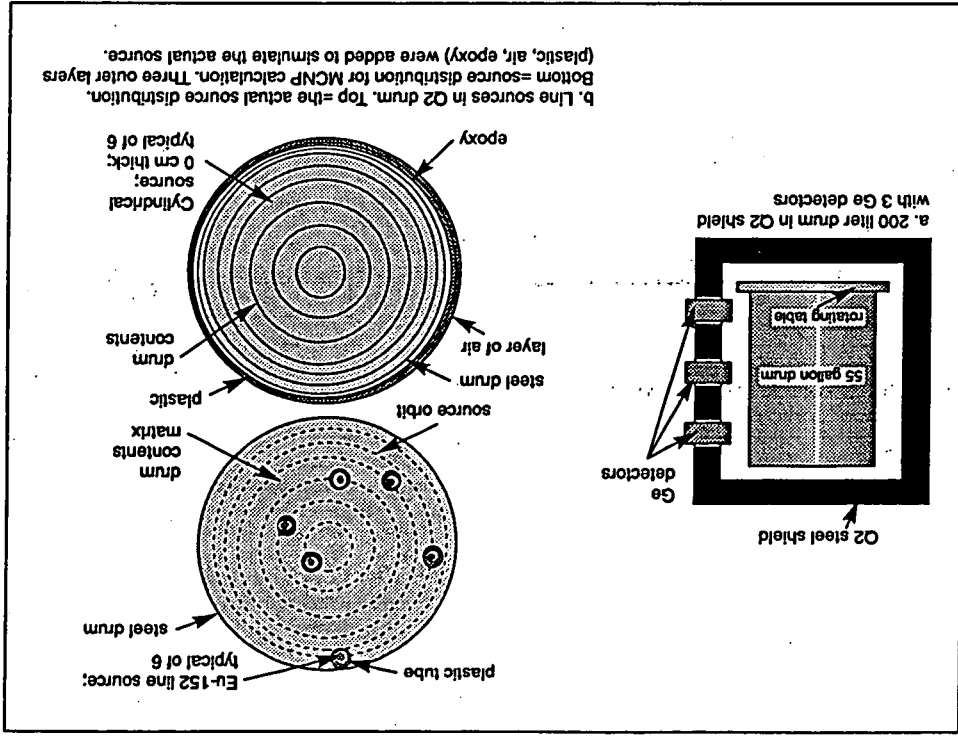
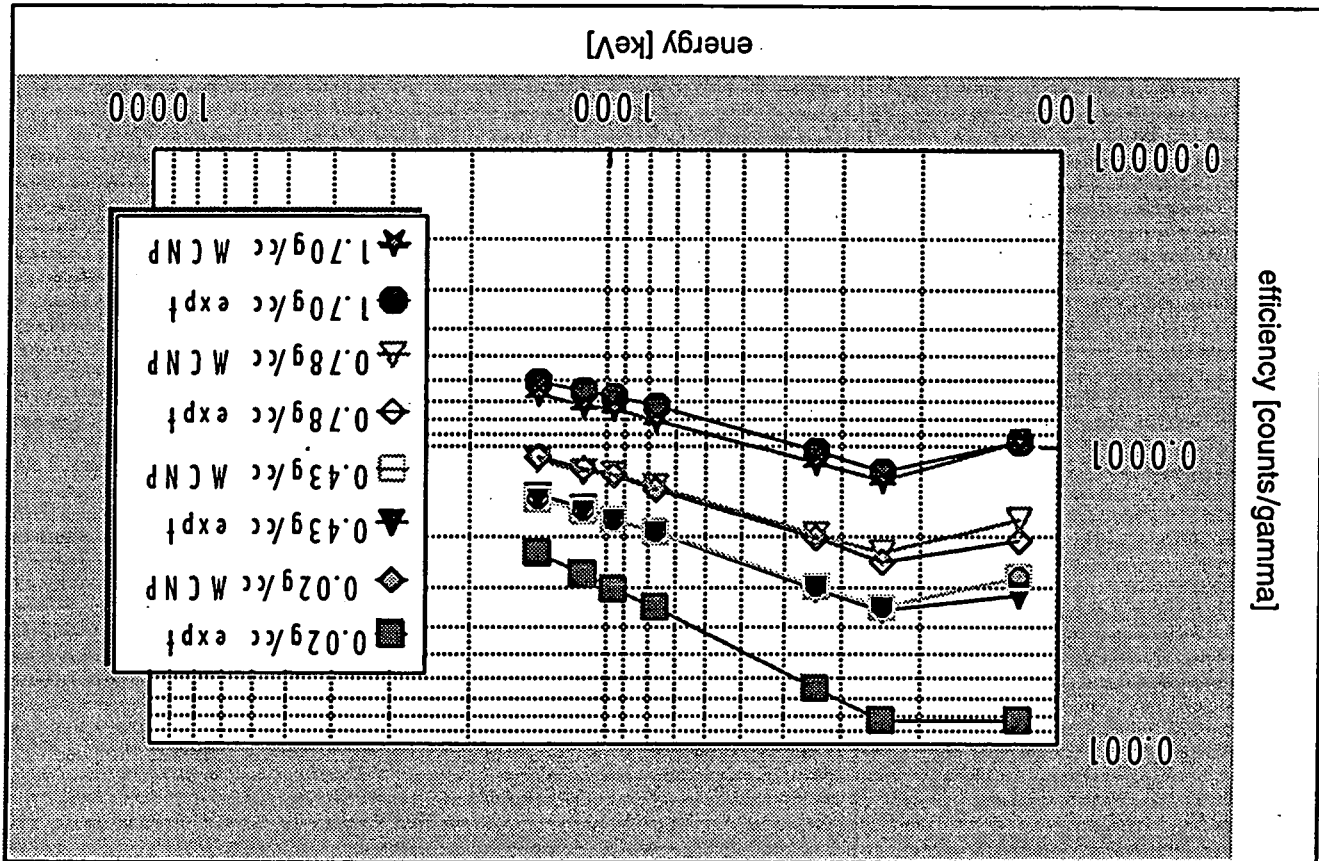


Figure 3. Heavily Shielded Source.

Figure 4. Q² Waste Assay Counter.



The calibration geometry used by Canberra is shown in Figure 4(b). It is intended to simulate a uniformly distributed source, but without the expense of constructing four different radioactive calibration drums. Six line sources are placed at six different radial positions in a non-radioactive drum. The radial distances are each at the center of six concentric hollow cylindrical volume elements, with each volume element containing 1/6 of the drum volume. Four different non-radioactive drums have been constructed, each with a different density. They have standard 200 liter drum shells, and are filled with foam (0.02 g/cc), cellulose board (0.43 g/cc), particle board (0.75 g/cc) and sand (1.70 g/cc).

This is a relatively difficult geometry to model because of the number of components involved. The cross sectional view of the 200 liter drum is shown in the top drawing of Figure 4(b). The line sources are Eu-152, similar to those used in Experiment 3. The source is enclosed in a plastic tubing of 7/8 in. O.D., 11/16 in. I.D. and 33 in. length. The drum rotates with a constant velocity through many rotations while being counted. But, since MCNP is not capable of simulating a rotating source, the six rotating line sources in the drum were approximated by six uniform cylindrical sources with zero thickness. The plastic tubes and source matrices were modeled by adding the appropriate cylindrical layers outside the drum as shown in the bottom drawing of Figure 4. Since the six Eu-152 line sources have similar activity (about 3% difference). The gammas have equal probability to be emitted from the cylindrical source surfaces.

Because of the low geometric efficiency, and the high probability for photon absorption, the calculation time would be extensive, even when the standard directional biasing is used. The MCNP general purpose source definition input card only allows the user to bias all of the photons in a single direction and within a single conical angle. But, since the geometry is quite variable depending upon the starting location of the photon in the source, it was necessary to prepare a special subroutine to more efficiently do this task. In this subroutine, each photon is focused toward the detector in its own biasing cone. The size of the biasing cone is variable, and depends upon the

location of the origin of the photon. The cone completely encompasses the detector. The biasing fraction for each photon is cumulated during the run. After the computations are complete, the biasing is removed with this cumulative factor.

The results are graphically displayed in Figure 4. For densities 0.02, 0.43 and 0.76 g/cc, except the energy 122 keV, the agreement between MCNP and experiment is quite good. Except for the 122 keV data points, all others are within one standard deviation and less than 6% bias. For the 1.7 g/cc density, MCNP shows a consistent bias of approximately 10% (except 122 keV). It is suspected that this bias may be caused by one or a combination of errors in the source measurement. Likely candidates are errors in the true drum size (there was a slight difference in size among the drums which we did not include in the model), the geometrical placement of the drum during the calibration, and/or imprecise knowledge of the true physical location of the outer line source in the drum.

CONCLUSIONS

A series of benchmark tests have been conducted to validate use of MCNP for efficiency calibration of Ge detectors for simple and complex geometries. The analyses result in the following conclusions.

For accurate efficiency calculations, especially at low energies, it is critical that the source and detector model be complete. All source and detector dimensions must be known and entered into the model. The density and elemental composition of the source, the detector, and any intervening absorbers must be accurately known. For example, we have found it necessary to use approximately 20 parameters in the model just to define the detector, mounting structure, and endcap.

For Ge detector peak efficiency, and for energies above 200 keV, MCNP is capable of achieving better than 10 % accuracy (all tests with the exception of Q^2 at 1.7 g/cc density) in a reasonable amount of computer time (less than 24 hours for an AXP), with the use of directional biasing. Abandoning directional biasing can keep the accuracy within 10% down to 100 keV, but at the expense of 10-100 times longer computer time.

It is easy to make mistakes in using MCNP. The program is not user friendly. Many physical parameters of the source and the detector must be entered to adequately describe the source-detector geometry. While there are some complementary software programs to provide some degree of error checking of the model, nothing can replace careful multiple checking of all input parameters, and reality checks of the results. First to verify the detector model, we compute a point source efficiency for a source on the detector axis, and at 90 degrees. This is then verified with a multi-energy source measurement. We then independently do something to check the source geometry, (e.g. reduce it to a point source or comparison the results to a previous good calibration).

MCNP, when used properly, is likely to be more accurate for efficiency calibrations of large and complex sources than calibration standards created for such geometries. For small well defined geometries at unit density, it is easy to obtain 3% calibration sources. However for small sources of other than unit densities, for sources with large volumes (tens to thousands of liters), or for complex shapes (long rods, large flat plates, cylindrical shells, etc.), the additional errors in source distribution and fabrication and calibrations are likely to be larger than the 10% MCNP accuracy demonstrated here. And, when a calibration using MCNP run is completed, there is no radioactive disposal cost. It is our plan to make MCNP the calibration method of choice for the large geometries in our gamma spectroscopy Waste Assay product line.

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Mathematical Calibration Of Ge Detectors, and the Instruments That Use Them

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ABSTRACT

Efficiency calibrations for Ge detectors are typically done with the use of multiple energy calibrations sources which are added to a bulk matrix intended to simulate the measurement sample, and then uniformly distributed in the sample container. This is rather easy for common laboratory samples. But, even there, for many environmental samples, waste assay samples, and operational health physics samples, accurate calibrations are difficult. For these situations, various mathematical calibrations or multiple source calibration techniques are used at Canberra. DOE-EML has pioneered the use of mathematical calibrations following source-based detector characterization measurements for *in situ* measurements of environmental fallout. Canberra has expanded this by the use of MCNP for the source measurements required in the EML technique. For other calibration situations, MCNP was used directly, as the primary calibration method. This is demonstrated to be at least as accurate as source based measurements, and probably better. Recently, a new method [ISOCS] has been developed and is nearing completion. This promises to be an easy to use calibration software that can be used by the customer for *in situ* gamma spectroscopy to accurately measure many large sized samples, such as boxes, drums, pipes, or to calibrate small laboratory-type samples.

Mathematical Calibration Of Ge Detectors, and the Instruments That Use Them

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INTRODUCTION

Calibration the Traditional Way

Canberra is probably the worlds largest supplier of gamma spectroscopy systems, and as such has had much experience in detector calibration technology. The traditional, and still most accepted method, is with the use of radioactive sources. Consider the simple case of a laboratory counting system to count a 1 liter container of water. All the user needs to do is create an exact duplicate of sample and container, but with the addition of several appropriate radioisotopes. These radioisotopes are chosen with the following characteristics:

- Energies to extend below and above the range of interest;
- Adequate activity:
 - High enough to not require a long count time;
 - Low enough to not disturb the instrument response;
- Appropriate chemistry to not precipitate, plateout, absorb, or evaporate;
- Long enough half-life to allow preparation and measurement;
- Enough gamma rays to define the shape of the curve;
- Well known energies and yields;
- Decay chain without coincident emissions to preclude summing effects;
- A suitable mix of nuclides and activities for a single mixed-gamma source.

Although it is essentially impossible to have a perfect calibration source, there are several widely accepted mixtures that are commercially available and that we use frequently at Canberra as shown in Table I.

| Energy [keV] | Nuclide | Energy [keV] | Nuclide |
|--------------|---------|--------------|---------|
| 60 | Am-241 | 88 | Cd-109 |
| 122 | Eu-152 | 122 | Co-57 |
| 244 | Eu-152 | 166 | Ce-139 |
| 344 | Eu-152 | 279 | Hg-203 |
| 779 | Eu-152 | 392 | Sn-113 |
| 1112 | Eu-152 | 662 | Cs-137 |
| 1408 | Eu-152 | 898 | Y-88 |
| | | 1173 | Co-60 |
| | | 1332 | Co-60 |
| | | 1836 | Y-88 |

Table I.
Typical Calibration Sources used at Canberra

These sources have generally proven adequate for routine calibration of samples for environmental measurement, or for health and safety measurements. With the purchase of proper quality calibration sources and with care in the preparation of the standard, very good efficiency calibrations can be obtained. Sources of error in this process for a typical laboratory include:

- Uncertainty in yield (generally <3%)
- Calibration source accuracy (3-5% typically)
- Counting statistics (generally 1-2%)

- Errors in dilution (1-2%)
- Losses from plating, precipitation and other mechanisms (can be a serious problem for Am, Pu, Hg, Sn)
- Coincidence losses (typically <5%)

From these uncertainties, it would seem that calibrations in the 5-10% range would be quite easy. And if all the laboratory did was to count small samples of water, life would be simple. But most of the environmental laboratory samples are somewhat different from the calibration conditions, or have other conditions that make the calibration not completely representative of the sample.

- Samples can have a density from 0.001 - 2 g/cc, which makes mixable bulk calibration sources and matrices much more difficult to find;
- Sample matrices can have a Z that is different than water, which can cause rather severe problems at low energies, unless this is also present in the calibration matrix;
- When a non-liquid matrix is used, then uniformity of the radionuclide throughout the calibration standard is difficult to obtain or prove;
- Sample containers sometimes change shapes in the calibration process [e.g. when curing epoxy matrices], or change shapes during use, and may not be representative of the assay container.

Because of these differences between the traditional calibration source, and the typical environmental, waste, or operational radiation protection measurement sample, this leads to the more realistic [in the authors opinion] calibration error estimate of 10-25%, when compared to the actual sample.

Actually, for most of these applications, a 25% error is not much of a problem, but it is still appropriate for the laboratory to minimize the measurement errors as much as practicable.

Unique calibration sources are sometimes manufactured for each of these special geometries, but this can be quite expensive. Alternately, empirical calibration correction techniques are frequently used to extrapolate in density and/in Z from a measured calibrations standard. But these are of limited use since they only apply to a specific geometry.

When the laboratory must measure large samples, then these simple laboratory calibration techniques are no longer economical to use. We manufacture a large number of instruments that measure samples of sizes of 50 liters, 100 liters, 200 liters, 1000 liters and even 20,000 liters. These instruments are most commonly used for measurement of radioactive waste, measurement of TRU waste, or measurements to prove that the sample is suitably "not-radioactive". For these samples, the cost of procuring a series of standards with sufficient activity, mixing those standards with a suitable matrix, and then ultimately disposing of the large sources as radioactive waste can be prohibitive.

For some simple geometries (rotating cylinders) we have had much success with a series of line sources. For example, for our Q² System, and Waste Assay System, we have constructed a set of four 200 liter drums, each with a different bulk matrix. The density of these are approximately 0.01 (foam), 0.3 (cellulose), 0.8 (wood), and 1.6 (sand). In each drum, six parallel holes are drilled from top to bottom. Each hole is in the center of six concentric equal area elements of the full drum. Six line sources of Am-241 and Eu-152 are inserted into the holes. When the drum rotates, these six line sources adequately simulate a uniform cylinder (<±10%). We have also done this for a 1000 liter cylinder, but matrix and construction costs are high.

For many other geometries, we have simulated a uniform concentration with a large number of point sources, as shown in Table II. While this was certainly successful at the time, it still was rather difficult and expensive, and problematic at low energies (<200 keV).

| Application | # Sources | Nuclides |
|--|-----------|-------------------|
| Livermore Lung for U/Pu <i>In Vivo</i> Lung calibration | ~1000 | Am-241, Eu-152 |
| Lamb/Sheep/Cow phantom | ~100 | Cs-137, Co-60 |
| Person with variable weight (50-200 kg) | ~1000 | Eu-152 |
| 200 liter drum with variable density [0.2 - 1.6 g/cc] | ~200 | Am241, Eu-152 |

Table II.

Calibrations with Multiple Point Sources

Most of the problems and/or expenses identified in this section can be avoided by the use of a properly implemented mathematical calibration procedure.

MCNP Mathematical Calculations

Having experienced the difficulties calibrating of these moderate sized samples, and planning to build systems to count even larger and more difficult samples, we started investigating full mathematical calibration tools about three years ago. Our goal was to have a design and development tool to help us optimize the number of detectors, their size, and the detector placement strategy.

A potentially useful tool would be Monte Carlo modeling. MCNP [1] is a well known general-purpose Monte Carlo code commonly used for neutron transport applications. It is also capable of modeling photon problems. There have been a few very useful publications describing the use of MCNP to model gamma ray spectra and efficiencies for Ge detectors [2, 3, 4, 5]. However, these have generally evaluated fairly simple detector-source geometries, or they have not performed direct efficiency calibrations. Important issues such as what are the critical parameters, how much detail is necessary in the model, etc. have not been studied, or reported.

During this evaluation, a series of experiments was conducted. Each experiment compared an efficiency computed with MCNP to another efficiency measured with a radioactive source in the same geometry. The most simple case was done first (point source on the axis for a Ge detector). Eventually, usually after several iterations, we achieved suitable agreement, and then went on to a more complex geometry. The sequences of events is shown in Table III. When there was initial disagreement between the two calibrations, the causes can be explained and solved as described in Table IV.

| |
|---|
| Point source on axis of detector |
| Point source at 45 degrees |
| Point source at 90 degrees |
| Line source |
| Planar source |
| Heavily attenuated point source with various attenuator thickness |
| Small complex source - Marinelli beaker |
| Large complex source - 200 L drum, 4 densities, 3 detectors |

Table III.

MCNP Validation Testing Sequence

| Problem | Solution |
|---|--|
| Inadequate model of the detector | Increase the complexity of the Ge detector model. Ultimately, we used 23 dimensions to describe the detector, holder, and endcap |
| Inadequate model of the source | Increase the complexity of the source, the container, and all other absorbers |
| Human error; e.g. incorrect understanding of MCNP or incorrect data entry | Vigilant proofing, use of tools to visualize the geometry [where available], and benchmarking to know reference points |
| Poor quality reference sources; even though all were traceable to NIST and allegedly with errors of <5%, 3 of the 11 source geometries had errors from 10-30% | Benchmarking unusual geometry calibration sources against other sources |

Table IV:
Problems Discovered and their Solutions

But we did certainly learn how to use MCNP and validated it as a useful calibration tool. It is now frequently used by Canberra in for a variety of equipment design, testing, and calibration purposes.

IN SITU GAMMA SPECTROSCOPY OF SOIL

One of the most common applications of mathematical efficiency calibrations is in *in situ* Ge gamma spectroscopy of radionuclides on the near surface of soils. This is performed by placing a Ge detector at a standard position [commonly 1 meter] above the soil. Then the "sample" is counted, as shown in Figure 1.

Because of the very large sample size, detection sensitivity is quite comparable to that of laboratory measurements. Typical detection limits easily obtainable with common equipment are listed in Table V. This used a 15 minute count time over typical New England soil. Additional advantages over the traditional sample collection and laboratory measurement are approximately 1/2 the cost [6], immediate results, and better accuracy with non-uniform radioactivity distributions.

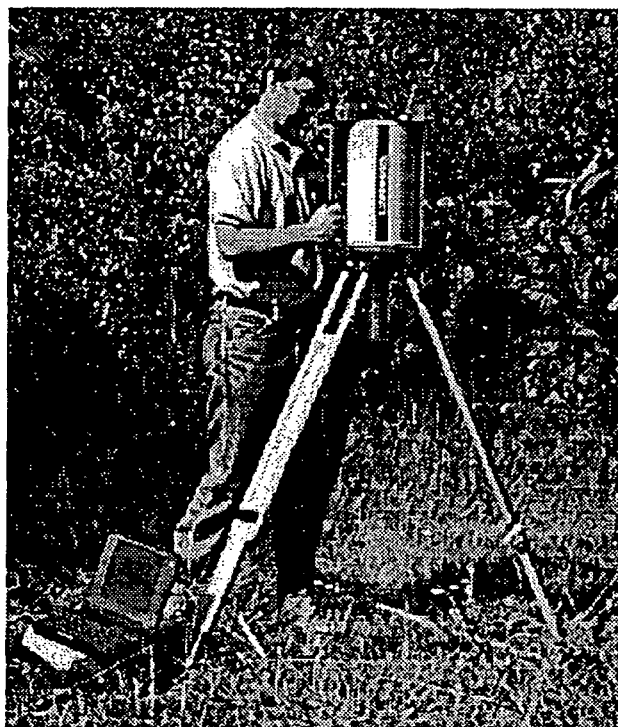


Figure 1
Typical *In Situ* Environmental Measurement

| Nuclide | LLD pCi/g | LLD Bq/g |
|-----------------|--------------|-------------|
| Co-60 | 0.05 | 0.002 |
| Cs-137 | 0.05 | 0.002 |
| Eu-152 | 0.2 | 0.007 |
| U-238 [Th-234] | 8 | 0.3 |
| U-238 [Pa-234m] | 3 | 0.1 |
| U-235 | 1 | 0.04 |
| Am-241 | 1 | 0.04 |

Conditions of measurement:

15 min. count time over typical New England soil
40% coaxial Ge detector at 1 meter above ground
Uniform radioactivity distribution in soil

Table V.
Typical *In Situ* Detection Limits

The most common calibration methodology is that of EML-300 (originally HASL-300). This is not a purely mathematical calibration, but instead uses a combination of radioactive sources and mathematical conversions. The user measures a multiple energy calibration source at 1 meter on the detector axis. Then repeated measurements are made at 1 meter and in 5° increments from 0 to 90°. Finally, a mathematical conversion is used to integrate the energy and angular response function into an efficiency calibration equation.

This calibration method has been very widely used and demonstrated to adequately represent simple distributions of radionuclides in the soil under the following conditions:

- Detector at the calibrated distance from the soil (typically 1 meter);
- Soil in an infinite flat horizontal plane;
- Radionuclides uniformly distributed in all radial directions out to nominally 20 meters;
- Vertical distribution in the soil represented by a single exponential, with the maximum at the surface.

While these assumptions are generally valid for environmental measurements in open areas with fresh

fallout, they may not be applicable for environmental mediation measurements. Old depositions generally have a maximum somewhere below the surface. Weathering of the soil likely has reduced the surface contamination levels, and/or clean dirt/sod/coverings may have been added to the top.

While the full EML-300 technique uses radioactive sources to individually characterize each detector, a simplified technique was developed by Helfer and Miller at EML [7] which required no sources. This is basically an empirical calibration that is based upon the individual EML-300 calibration of approximately 40 detectors. The required data is diameter and height of the Ge detector element. This generic calibration methodology is used in some commercial software [Ortec M-1]. For many applications, this calibration is sufficient, but the user must be aware of these limitations:

- All mentioned in previous section;
- Calibration validated only for detectors of <45% relative efficiency;
- Calibration validated only for energies >200 keV;
- Calibration validated only for detectors with diameter:height ratios close to unity.

Because these limitations are commonly considered too great by our customers, and because the required multi-energy calibrations sources and measurements are difficult and easily inaccurate, Canberra has developed a combined MCNP/EML method. Each detector is individually calibrated, thus avoiding the generic calibration problems noted above. The point source measurements are replaced by MCNP computations. A theoretical point source is placed at each of the 10 radial locations. Energies from 50 keV to 3000 keV are used in the point source "measurements". Then the data is integrated and converted following the EML-300 technique into the 32 different calibrations that are delivered to each customer.

To validate this methodology comparisons were done between full MCNP and the MCNP-EML technique. Figure 2 shows the results for the uniform distribution geometry. The agreement is within 1% average and within 11% worst case. Similar agreement was obtained for the other three vertical distributions

computed. The major advantage of the MCNP-EML technique is computer time. MCNP computations for large samples take much computer time. The data in Figure 2 required several days time for a fast AXP computer, even using the various speed tricks we have learned. And this is just for 1 of the 32 calibrations delivered with the *in situ* system.

Full MCNP Efficiency Calibrations

But most geometries are not suitable for the simplified techniques described in the previous section. They are not very easy to numerically integrate. For these, we use the full MCNP computation, even at the expense of multiple days of computer time per run. This code has been extensively tested by Canberra with a series of validation comparisons to mixed gamma energy calibration sources [8]. We have shown MCNP to be

consistent with source based calibrations to within 10% for energies >200 keV and to within 15% for energies between 60-200 keV. A few of the calibrations that have been done with MCNP are described next.

In situ well logging detector

For this application, the Ge detector is placed in a water-tight housing, and lowered down a hole in the ground, as shown in Figure 3. Measurements are made at various depths. Sometimes the detectors are uncollimated. Other times, they have internal or external shielding to limit the field of view to a known area. Previously, Canberra has calibrated these with a fixture containing approximately 100 tubes of Eu-152 in a plaster matrix, however MCNP was used most recently.

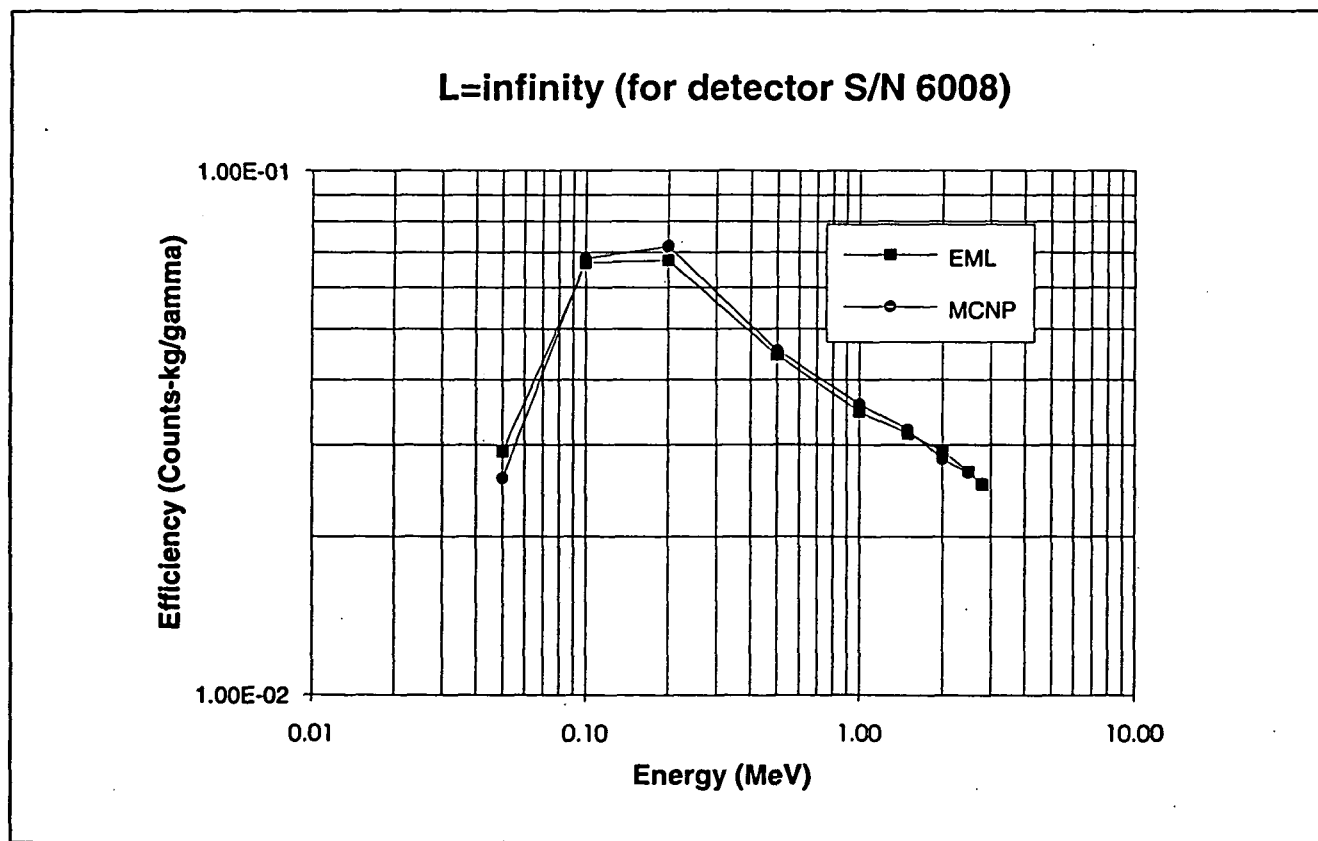


Figure 2.
Comparison Between MCNP and MCNP-EML In Situ Calibration



Figure 3.
Ge Detector being used in Well Logging Application

Large Box [and other] Counter

This product consists of four shielded and collimated Ge detectors, all counting the sample, but from different directions. Figure 4 is a composite showing the detectors of a manual box counter in the photos, and a drawing of the mechanism for an automatic system where the detectors move. The spectra are generally summed for analysis, but can be analyzed separately. The sample is a B-25 box, typically 4' x 4' x 6' in size. These were modeled with MCNP in four different densities to bracket the range of samples expected. Calibrations were also done for B-12 boxes [2' x 4' x 6'] and for a pallet of four 55 gal drums.

Portable Ge detector for B-25 Box field measurements

This customer is Canberra's Applications Services Group. They had a project to measure B-25 boxes of soil for Pu-238 to determine if they were TRU or not. A portable Ge detector with collimator was calibrated. Calibrations were done for the box with uniform radioactivity distribution. And to investigate the effect of non-uniform distributions of radioactivity, a variety of other point source distributions were also calibrated. Figure 5 shows the detector in use at the project site.

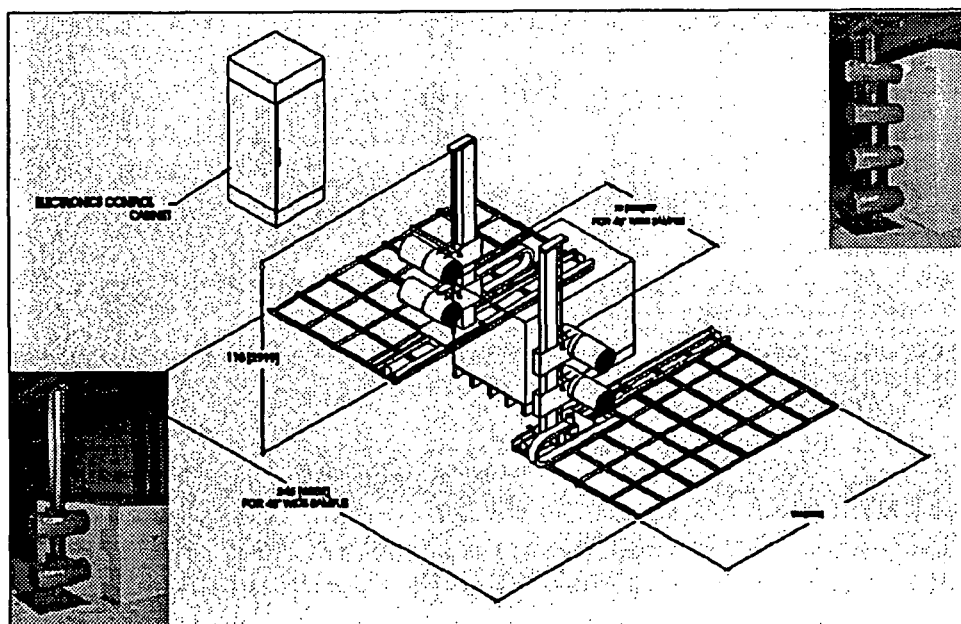


Figure 4.
Box Counter for Large and Very Large Samples

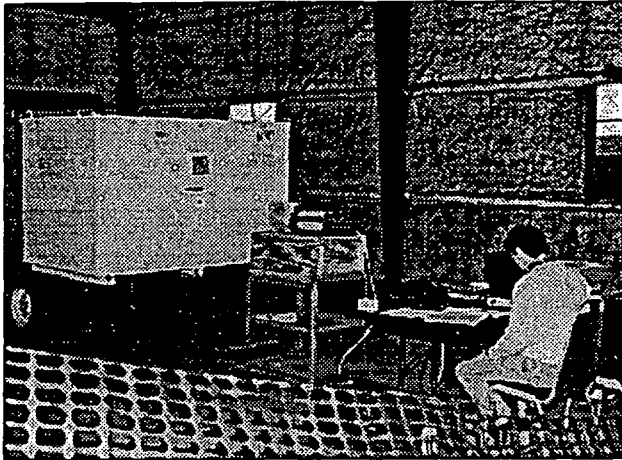


Figure 5.
Portable Ge Detector Counting B-25 Boxes

High Volume Soil Sorter System calibration and LLD determination

This system can count 50 tons of radioactive dirt per hour and is shown in Figure 6. The dirt is on a moving conveyor belt through a shield, where it is viewed by two large Ge detectors. A mathematical model was made of the dirt and of the shield. Efficiency computations were performed and used to determine the best placement of the detectors. Then, full energy spectral computations were done to determine the LLD of the

system. MCNP is not yet suitable to model the cosmic contribution to background, but in this case, the background is nearly all from the natural Radium, Thorium, and Potassium in the sample itself. Therefore the background is from the Compton continuum of these radionuclides, which can be properly computed by MCNP. We have also developed a technique to modify the MCNP output to add noise, and make it statistically resemble the expected Ge peak shape. We then convert these spectra into our MCA format and analyze them with our Gamma Spectroscopy software. This gives a very reliable prediction of the actual instrument performance.

ISOCs, *In Situ* Object Counting System

This is a new product that is only practical because of mathematical calibrations. Various combinations of techniques now make it practical to do laboratory quality measurement of samples [small and large] in the field. This is an ideal instrument for decontamination surveys, environmental measurements, emergency response teams, light use waste assay measurement, and regulatory inspection teams.

The Ge detector is mounted on a portable cart to allow it to be transported and aimed at the sample to be counted. Various collimators and side shields and back shields can be added to reduce interference from

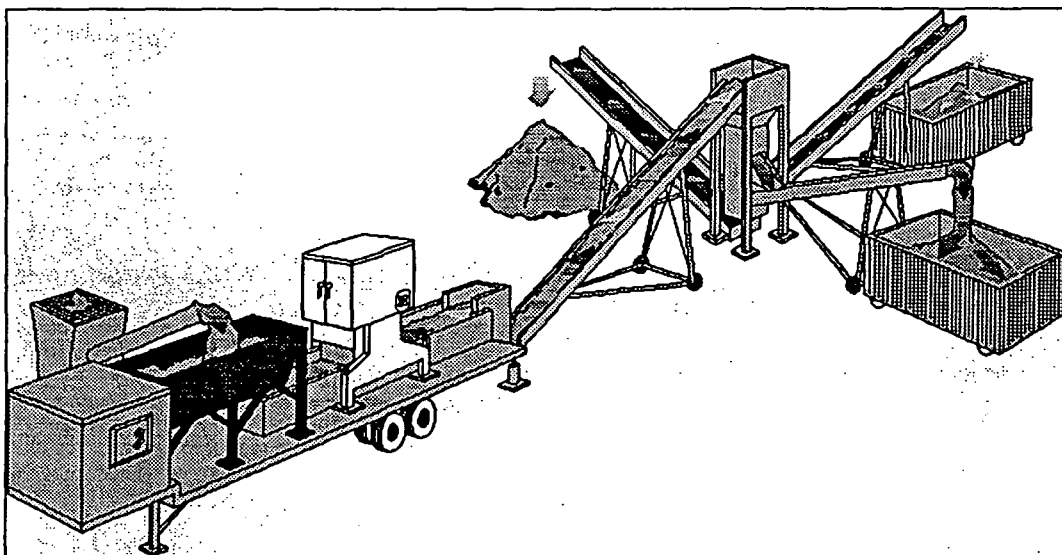


Figure 6.
High Capacity Spectroscopic Dirt Counter and Sorting System

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other nearby radioactive items, and to define the field of view of the detector. Figure 7 shows the detector and shield and transportation cart.

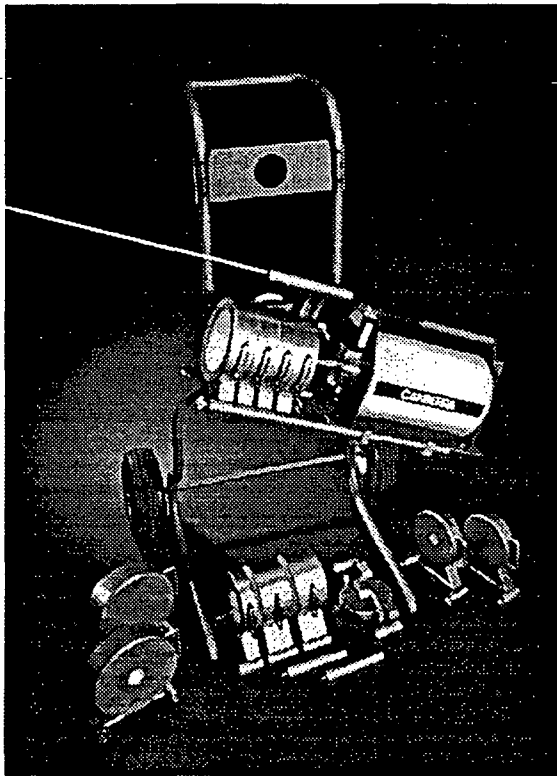


Figure 7.
ISOCS Shield System and Detector Carrier

Because of the very wide range of samples to be encountered in the typical use, the solutions before with pre-defined efficiency calibrations are not practical. So, for this product, the mathematical calibrations are performed by the customer. But, to make this process work accurately, each individual detector is first characterized by Canberra. The results of that individual detector characterization are delivered to the customer as a part of the calibration software. Multiple detectors can be characterized and selected for use by the customer. MCNP is used by Canberra for this characterization process. The output of the process is a series of equations that defines the detector response at any point from the endcap to 50 meters radius, at any energy from 50-7000 keV, and at any angle in all 4π directions.

When the user wants to do a calibration, it is a simple process taking only a few minutes. First, a template resembling the generic sample shape is chosen. Nine such templates are available:

- Simple box [basic box from point size up to many m^3]
- Complex box [allows various non-uniform source distributions]
- Simple cylinder [basic drum from point size up to many m^3]
- Complex cylinder [allows various non-uniform source distributions]
- Circular stacked planes [cylinders viewed on end, and *in situ* soil distributions]
- Rectangular stacked planes [walls, floors, ceilings]
- Pipe [source inside pipe in various locations]
- Marinelli Beaker or Well [detector inside source container]
- Sphere [basic object with source as volume or shell]

Each of these basic shapes has many parameters that can be used where necessary to create many variations. After selecting the template, the various critical parameters that define the sample-detector geometry are measured [or estimated] and entered.

If the detector is using one of the ISOCS collimators, then the appropriate one is selected, and the parameters defining it are entered into the software. Otherwise, the user can enter them.

All materials must be defined so that the proper attenuation corrections can be made. ISOCS contains the full cross-sections of all chemical elements. And it has a materials library containing common construction materials, and the tools for the user to create others not already defined.

Finally, the user instructs the ISOCS program to compute the efficiency vs. energy datapoints. This process takes from 10-30 seconds [normally] up to 5-10 minutes [large sources, multiple sources, and/or

narrow collimators]. The output is then converted into the Genie-PC efficiency curve and is now available for use in the analysis of the spectrum.

Currently underway is the validation of this efficiency calibration software. Comparisons are being made to MCNP computations for identical objects, and to source measurements. A few examples are shown in Figure 8.

The accuracy of the ISOCS efficiency computation method is nearly as good as the full MCNP computation for common and simple geometries, and perhaps a factor of 2-3 worse for very large sources and/or heavily collimated sources. But the accuracy is expected to be more than adequate for the field measurements where the primary use is expected. And, in our experience from the construction of these large radioactive calibration sources, the ISOCS calibrations probably just as accurate [maybe even better].

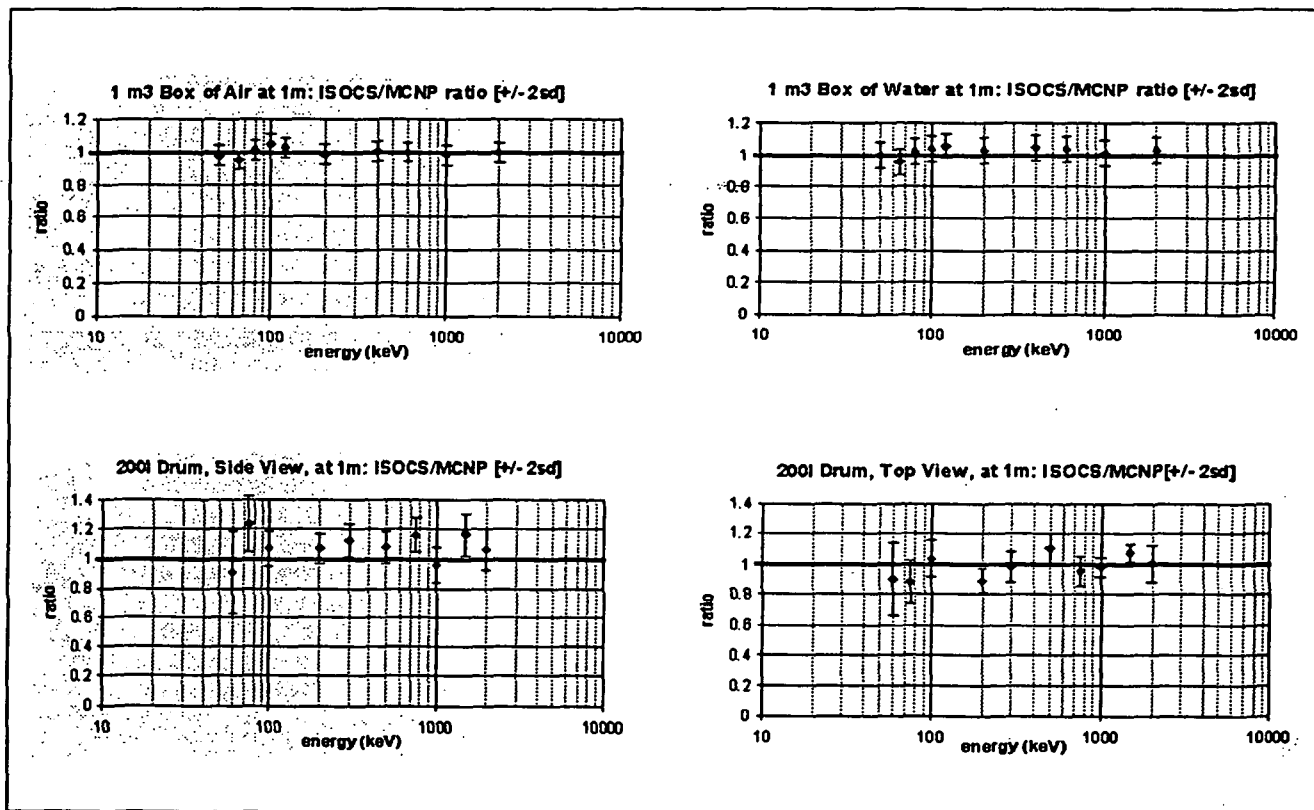


Figure 8.
Typical ISOCS Validation Testing Data

CONCLUSION

Mathematical calibrations have been shown to be a suitable alternative to the traditional method of duplication of the sample with multiple energy radioactive sources. For simple laboratory-sized samples containing water-equivalent samples, the use of radioactive sources is still the least expensive and most accurate method. However, when any of the following conditions are present,

- unusual densities
- unusual sample bulk matrix
- large sample
- sample to be counted in low efficiency position

the use of mathematical calibrations may well be more accurate, and will most likely be quicker and less expensive. The problem remains today, however, that mathematical calibrations are still not widely accepted, and must be well documented and proven to be acceptable to the ultimate customer and any of his reviewers. However, it is speculated that as the use becomes more common and more refined, that mathematical calibrations will be the preferred option a few years from now.

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ISOCS Mathematical Calibration Software for Germanium Gamma Spectroscopy of Small and Large Objects.

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ISOCS [*In-Situ* Object Counting System] is a portable Ge gamma spectroscopy instrument designed to quantify gamma emitting radionuclides in various sized and shaped objects. The ISOCS instrument consists of a Ge detector, a series of collimators mounted on a transportable cart, the InSpector portable MCA, a laptop PC with GeniePC gamma spectroscopy software, and the ISOCS efficiency calibration software.

With this new portable instrument, the user can now measure the radioactivity content of complete objects, large or small. The successful implementation of this device provides many advantages over the traditional methods of sampling, followed by laboratory analysis.

- Results are available nearly instantaneously;
- Where the object is not homogeneous, the ISOCS results are probably more accurate, since a very large fraction of the sample is measured;
- Detection limits are as low or lower, since a very large sample size is used.

Figure 1 shows the ISOCS used to measure a barrel lying on the ground, simulating a typical accident or D&D application.

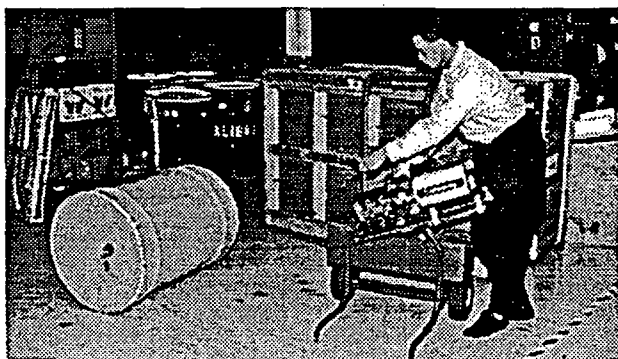


Figure 1. ISOCS used to quantify radioactivity in a 200 liter drum

This product is only practical because of the ISOCS mathematical efficiency calibration. Previous techniques that Canberra and others have used ¹ [uniform mixtures of radionuclides, large numbers of small sources in inert matrices, and MCNP ²³ Monte Carlo calibrations] are quite expensive to do, require much time to create, and generate expensive radioactive waste [except for MCNP].

Unlike previous simplified calibration software that treats detectors as points, each ISOCS detector has a unique calibration. This characterization is done by Canberra using MCNP as the reference. The results of that individual detector characterization are included as a part of the ISOCS calibration software. The output of the detector characterization process is a series of equations that define the detector response:

- at any point from the endcap to 50 meter radius,
- at any energy from 50 - 7000 keV, and
- at any angle in all 4π directions.

The ISOCS calibration is a simple process taking only a few minutes. First, a template resembling the generic sample shape is chosen. Nine such templates are available:

- Simple box
- Complex box
- Simple cylinder
- Complex cylinder
- Circular stacked planes
- Rectangular stacked planes
- Pipe
- Marinelli Beaker or Well
- Sphere

Each of these basic shapes has many parameters that can be used where necessary to create many variations. After selecting the template, the various critical parameters that define the sample-detector geometry are en-

tered. The collimator combination used is the selected from a list, or alternatively, the parameters are entered manually.

The composition and density of all materials must be defined so that the proper attenuation corrections can be made. The ISOCS materials library contains the full cross-sections of all chemical elements. Also included is a set of common materials [concrete, sand, dirt, wood, water, plastics, etc.]. It is a simple task for the user to create additional materials for addition to the library. The materials editor allows materials to be defined by entry of the chemical formula, by entry of the percentage each element, or by percentage combinations of previously defined materials.

Next, the geometrical relationship between the detector and the sample must be defined. Normally, this is just the distance between the detector and the sample, but several other dimensions are available when the object is not on the axis of the detector, and/or when the detector is not pointing at the center of the object.

Then, the user instructs the ISOCS program to compute the efficiency vs. energy datapoints. During this process, input information is checked, and the efficiency is integrated over the sample volume, corrected for sample self attenuation, container or air attenuation, and collimator attenuation. This process takes from 5-30 seconds [normally] up to 5-10 minutes [large sources, multiple sources, narrow collimators, and/or slow computers].

The output of the ISOCS process is a set of energy/efficiency/error triplets. Upon exiting the ISOCS user interface, this data is converted into the GeniePC energy-efficiency curve format and is displayed for the user to accept/edit and store for future use in sample analysis.

The validation process is nearing completion. A large number [>50 so far] of multi-energy comparisons are being made between the ISOCS efficiency and a reference efficiency. Where possible, we are using traceable sources for comparison. But, most of the difficult validations will be by comparison to MCNP computations for identical objects. MCNP has been shown ³ to be capable of accuracy of 10% or better, when properly applied.

The accuracy of the ISOCS efficiency computation method appears to be approximately <10% for energies >200 keV, <20% for 50-100 keV. Heavily collimated sources will be worse, perhaps a factor of 2. The ISOCS accuracy is expected to be more than adequate for the field measurements where the primary use is expected.

The ISOCS calibration software is quick, efficient, and accurate. For simple laboratory-sized samples containing water-equivalent samples, the use of radioactive sources is still the least expensive and most accurate method. However, when any of the following conditions are present:

- unusual densities
- unusual sample bulk matrix composition
- large samples
- samples at far distances
- heavily attenuated samples

the ISOCS calibration method will be cheaper, quicker, and probably more accurate than traditional source-based calibrations.

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ISOCS, A LABORATORY QUALITY GE GAMMA SPECTROSCOPY SYSTEM THAT YOU CAN TAKE TO THE SOURCE FOR IMMEDIATE HIGH QUALITY RESULTS

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ABSTRACT

The currently accepted methodology for most radiological assessments is a combination of gross [non-nuclide specific] measurements, and sampling followed by laboratory analysis. Many problems with this scenario could be solved by good quality and practical *in situ* Ge gamma spectroscopy, such as:

- Reducing the large potential errors from non-homogeneous source distributions;
- Reducing the cost and improving the safety by minimizing the sampling process; and
- Essentially eliminating the delay time between "sampling" and having nuclide-specific quantitative results.

There have been many advances in nuclear instrumentation in the past 10 years that now make it practical to do field sample-based gamma spectroscopy, and in-situ gamma spectroscopy.

These advances include:

- Large Ge detectors for easy and positive nuclide identification at low levels;
- Multi-Attitude Cryostats [MAC] for pointing the detectors in all directions;
- Rugged cryostats that have 2-5 days holding time;
- Laboratory quality battery operated computer controlled portable MCAs;
- Portable PCs with tremendous computation power;
- Sophisticated, reliable, and easy to use gamma spectroscopy programs.

These items now make it possible to take a Ge detector to the field and count and analyze samples, and identify radionuclides. But [in the past] if quantification was necessary, then calibrations had to be done with radioactive sources for each specific geometry. For samples in defined laboratory-sized containers, that wasn't too difficult. But for large or complex samples, this was rather difficult and expensive.

This difficulty has now been eliminated, by the use of the ISOCS mathematical [sourceless] efficiency calibration process. Now, all the user must do is enter a few physical measurements that describe the source, any absorbers, and the source-detector location. Then, the calibration computation is performed in a few minutes and is available for use.

Calibrations can be performed for a wide range of "samples". These include boxes, drums, pipes, walls, floors or the ground, ceilings, holes in the ground, etc. Basically most any shape of sample can be calibrated at any energy from 50 keV to 7000 keV, at any direction from the detector, and at any distance from 0 to 50 meters from the detector. A flexible collimator/shield package has also been designed to complete this field instrument.

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INTRODUCTION

In situ gamma spectroscopy has been around for many years. But until recently, these were rather heroic adventures. For adequate sensitivity, NaI detectors were commonly used, but these suffer problems of poor resolution, and thermal instability. The poor resolution of these detectors, combined with the complex environmental background spectrum from Radium, Thorium, and Potassium-40 made it essentially impossible to find very low levels of other radionuclides, such as Cs-137, U-235, and U-238. Germanium detectors then came along, but with problems of their own. Up until approximately 15 years ago, most were Ge(Li), which meant that they could never be removed from liquid nitrogen, or the user was left with an expensive desk ornament. But now intrinsic Ge detectors can be warmed up when not in use. These detectors must be cooled with liquid nitrogen (LN) to operate, but that is not much of a problem today. The advance of TIG and MIG welding has made LN available most anywhere in the world. For portability, we now have LN cryostats that hold 2 or 5 days of LN supply. And special cryostats like Canberra's MAC or BigMAC are Multi Attitude, which allows the detector to be in all directions [up, sideways, and down].

While *in situ* gamma spectroscopy with Ge(Li) detectors has been done even 25 years ago, the small [and expensive] detectors available then made it not a very practical tool. But today, Ge detectors are commonly available in sizes that make count times rather short. A 40% - 50% relative efficiency detector [approximately 5-6 cm diameter x 5-6 cm high] is a good general purpose size for most applications. Detectors are available up to nearly 3x larger for high sensitivity; and where measurement of very high activity sources is required, special very small detectors may be necessary to keep within the dynamic range of the electronics. For subsurface measurements, water-

proof containers are available; for well-logging applications, special narrow diameter cryostats are available to go down small holes.

But it is the revolution in small electronics which resulted in small and incredibly powerful battery operated portable Multi Channel Analyzers and PCs that have made *in situ* gamma spectroscopy practical. Now, instead of an instrument rack of equipment and an electric generator, the user can carry in 1 hand the same equipment. And the computer is powerful enough to allow sophisticated software that does a nearly perfect job of de-convoluting the spectrum, correcting the data, and generating immediate answers.

These above items now are all commercially available. With them, the user can take the detector to the source, and easily obtain the identity of the nuclide. But for quantification of the nuclide activity, special efficiency calibrations must be made. And, if there are multiple sources of radioactivity in the area and only one is of interest, then special shielding must be used to isolate the item of interest from the other interfering sources. It is the solution to these 2 problems that has been developed which when integrated with the other items now make *in situ* measurements practical.

THE ISOCs INSTRUMENT

ISOCs [acronym for *In Situ* Object Counting System] is a portable Ge gamma spectroscopy instrument designed to both identify and quantify gamma emitting radionuclides in various sized and shaped objects. The ISOCs instrument consists of the following components:

- Ge detector of appropriate type, size, and shape for the application;
- Detector mounted in a Multi Attitude Cryostat so that it can point in all directions;

- Series of 25mm and 50mm thick shields each with various angle collimators to define the field of view of the Ge detector, and to reduce interference from other objects [see Figure 1];
- Sturdy and portable cart to allow detectors and shields to be transported to the measurement site and to aim the detector at the objects to be measured;
- InSpector, a portable battery-operated electronics package that includes the detector High Voltage Power Supply, amplifier, Analog-Digital Converter, and the Multi-Channel Analyzer;
- Portable Laptop Computer for sample information input, InSpector control, and data analysis and storage;
- GeniePC Gamma Spectroscopy software for spectrum deconvolution and nuclide analysis;
- ISOCS Efficiency Calibration software to allow quantitative analysis of a wide variety of samples.

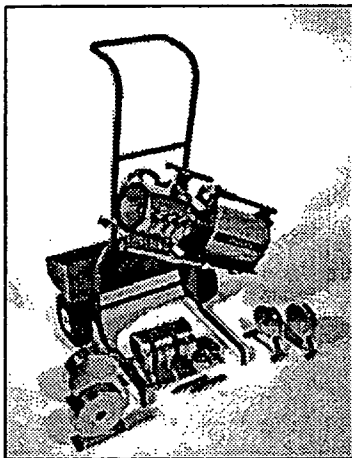


Figure 1.
ISOCS Shielding and Detector Transport System.

APPLICATIONS OF THE ISOCS INSTRUMENT

With this new portable instrument, the user can now measure the radioactivity content of complete objects, large or small. The successful implementation of this device provides many advantages over the traditional methodology, which is sampling followed by laboratory analysis.

- Results are available nearly instantaneously, which allows better decisions to be made. The results can be used to guide the selection of the next measurement for a more complete survey without

the necessity to remobilize the sampling crew. Or the results can be used to guide the conduct of a decontamination activity to know when to stop. The quick and reliable results are also very useful to advise interested members of the public and/or regulatory bodies that all is well.

- Most situations of radiological contamination do not result in uniform deposition of the offending material. Consequently, the selection of a small sample to send to the laboratory is a difficult and imprecise task. One solution is to take very large samples. And this is just what *in situ* measurement generally does. This large sample averages the non-homogeneity of the sample deposition over the entire object or area. Where the contamination on or in an object is not homogeneous, the ISOCS total activity results are probably more accurate than conventional samples, since a very large fraction of the sample is measured
- *In situ* minimum detection limits can also be quite good. They are generally as low or lower than laboratory samples, since a very large sample size is used.
- In many situations taking samples is very difficult and/or dangerous. Common examples are contaminated concrete, activated steel, radioactive liquids, corrosive or high temperature fluids, dusts and powders, sludge on the bottom of a tank, tightly adhered surface contamination, gaseous samples, etc. Then, these samples must be properly packaged and transported to the laboratory, where more handling is involved. *In situ* measurements can avoid this in many cases.
- Taking samples is also expensive. NUREG-1496¹ describes the cost of taking a sample, processing it, and laboratory spectroscopy. The same analysis is also done for *in situ* gamma spectroscopy. The sampling/laboratory analysis process is approximately 2x as expensive as *in situ* gamma spectroscopy. And, because of the non-uniform nature of the contamination in most cases, more samples must be taken than for *in situ* measurements.

This is an ideal instrument for decontamination surveys, environmental measurements, emergency response teams, operational radiation protection surveys before maintenance operations, occasional use waste assay measurements, and regulatory inspection teams.

One of the most common applications of *in situ* gamma spectroscopy is the measurement of radionuclides on or near the surface of soils. This is performed by placing a Ge detector at a standard position [commonly 1 meter] above the soil. Then the "sample" is counted, as shown in Figure 2. Because of the very large sample size, detection sensitivity is quite comparable to that of laboratory measurements. Typical detection limits easily obtainable with common equipment are listed in Table I. This used a 15 minute count time over typical northeastern USA soil. The resultant detection limits are quite suitable for most "free release" or "clearance level" concentrations that have been suggested. The ISOCS unit could be useful for a routine monitoring program to check for surface radioactivity, or in an accident response situation to prove that nothing was released or spilled.

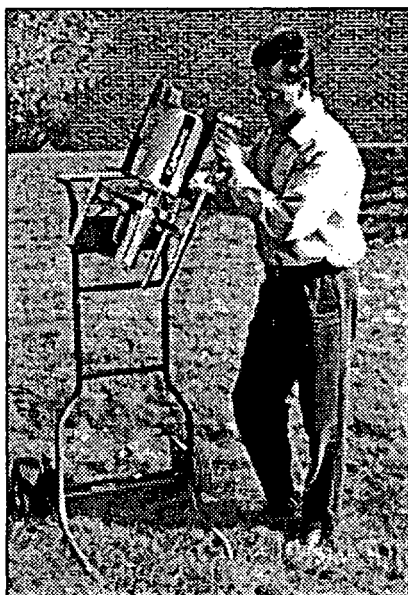


Figure 2.
Worker preparing for environmental soil *in situ* measurement.

Table 1, Typical Soil Detection Limits

| Nuclide | LLD pCi/g | LLD Bq/kg |
|-----------------|--------------|--------------|
| Co-60 | 0.02 | 0.8 |
| Cs-137 | 0.03 | 1.1 |
| Eu-152 | 0.1 | 3.5 |
| U-238 [Th-234] | 3 | 95 |
| U-238 [Pa-234m] | 2.8 | 110 |
| U-235 | 0.3 | 10 |
| Am-241 | 1 | 3.6 |

15 min. count time over typical New England soil
40% coaxial Ge detector at 1 meter above ground
Uniform radioactivity distribution in soil

For Decontamination and Decommissioning [D&D] activities, a common requirement is to measure the radioactivity on walls, floors, and ceilings. This labor-intensive task can be made easier by *in situ* gamma spectroscopy. For example consider a room that could potentially have surface contamination on the ceiling. An ISOCS unit can quickly measure this and report quantitative activity for each nuclide found, and the LLD of the important nuclides not found. Assuming a ceiling area of 3m x 3m, with the detector 2.5m below the ceiling, the limits in Table 1 can be obtained with a 60 minute count. The detection limit can be lowered by counting longer, by more efficient detectors, or by moving the detector closer to the source. A common use would be to make a quick evaluation of rooms that may have contained radioactive sources at one time. An unshielded detector in the center of the room is a rather efficient means of showing that gamma emitting sources are not present at significant levels. Since the detector has nearly uniform efficiency at all angles, hidden sources most anywhere in the room are likely to be found.

Table 2, Typical Room Surface Detection Limits

| Nuclide | LLD uCi | LLD kBq | dpm/100 cm ² | Bq/m ² |
|-----------------|------------|------------|----------------------------|-------------------|
| Co-60 | 0.08 | 2.8 | 190 | 310 |
| Cs-137 | 0.08 | 3.1 | 210 | 350 |
| Eu-152 | 0.35 | 13 | 900 | 1500 |
| U-238 [Th-234] | 3.4 | 130 | 8300 | 14000 |
| U-238 [Pa-234m] | 9.5 | 350 | 23000 | 40000 |
| U-235 | 0.17 | 6.4 | 430 | 710 |
| Am-241 | 0.85 | 32 | 2100 | 3500 |

60 min. count time for 3x3m plane source
40% coaxial Ge detector at 2.5 meter
Uniform radioactivity distribution on surface

Figure 3 shows the ISOCS used to measure a barrel lying on the ground, simulating a typical accident or sloppy D&D application. The ISOCS shield and collimator can be used to assure that only the drum will be measured, not the nearby boxes. Various collimators with 180, 90, and 30 degree fields of view are available to do this. With the same detector as in Table 1, with the 90 degree collimator; and at a distance of 1 meter from the drum, the detection limits in Table 2 can be achieved with a 15 minute count time.

Large boxes as shown in the background of Figure 3 are also used for shipment of radioactive materials. The ISOCS instrument can also be used to measure the radioactivity in these boxes. Very large boxes like

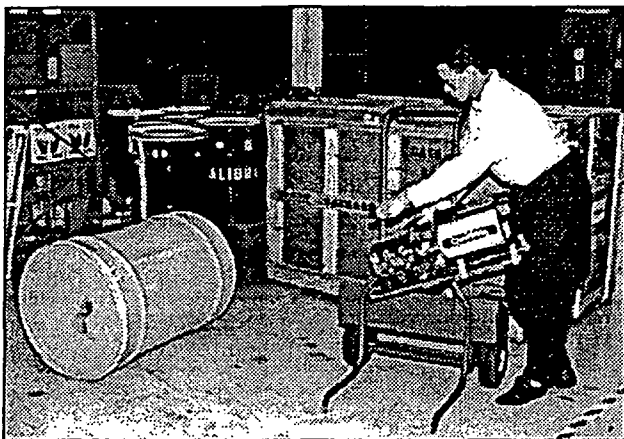


Figure 3.
ISOCS in use to quantify radioactivity in a 200 liter drum.

Table 3, Typical 200 L Drum Detection Limits

| Nuclide | LLD uCi | LLD kBq | LLD pCi/g | LLD Bq/kg |
|-----------------|------------|------------|--------------|--------------|
| Co-60 | 0.10 | 3.7 | 0.75 | 28 |
| Cs-137 | 0.17 | 6.4 | 1.3 | 48 |
| Eu-152 | 0.39 | 14 | 2.9 | 110 |
| U-238 [Th-234] | 4.5 | 160 | 34 | 1200 |
| U-238 [Pa-234m] | 12 | 460 | 94 | 3500 |
| U-235 | 0.25 | 9.1 | 1.9 | 69 |
| Am-241 | 13 | 490 | 99 | 3700 |

15 min. count time at 1 meter from 200 liter drum
40% coaxial Ge detector at 1 meter above ground
Uniform radioactivity distribution in drum

ISO-freight containers or large trucks can be measured. Because these boxes are so large, the best procedure would be to make multiple measurements around the accessible surfaces of the box, to reduce the possibility of missing a "hot spot". Typically, measurements would be made on a grid spacing of 1-2 meters. For the example shown here, 8 measurements were done at a distance of 1 meter from the surface, 3 on each side, and 1 on each end. Yes, theoretically it is possible to miss a small source located in the center of a large box. But if this is just a single isolated source in the entire box, then any normal sampling scenario will have even a lower probability of finding the source. Consider the case of a large refuse container that is only supposed to be used for disposal of "non-radioactive" material, as shown in Figure 4. The ISOCS unit could be used to survey this container to provide a legal record of the contents of the container. Table 4 shows that the detection limits are quite good, generally below what is commonly considered free-releasable.

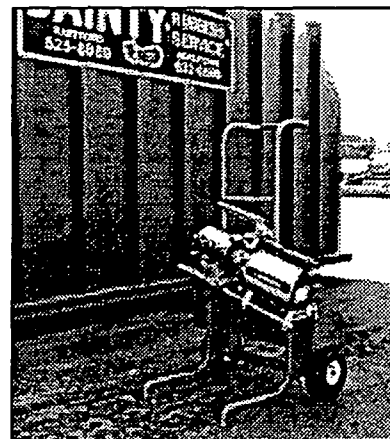


Figure 4.
ISOCS in use to assay a very large trash shipping container.

Table 4, Detection Limits for ISO shipping container

| Nuclide | LLD uCi | LLD kBq | LLD pCi/g | LLD Bq/kg |
|-----------------|------------|------------|--------------|--------------|
| Co-60 | 0.25 | 9 | 0.22 | 7.8 |
| Cs-137 | 0.36 | 13 | 0.32 | 12 |
| Eu-152 | 1.1 | 40 | 1.0 | 36 |
| U-238 [Th-234] | 50 | 1900 | 44 | 1700 |
| U-238 [Pa-234m] | 34 | 1300 | 30 | 1100 |
| U-235 | 1.3 | 50 | 1.2 | 43 |
| Am-241 | 60 | 2200 | 51 | 1900 |

8 measurements of 15 minutes, 3/side, 1/end
Container = 2.5m x 2.5m x 6m filled with 0.3g/cc wood
40% coaxial Ge detector at 1 meter with no shield
Uniform radioactivity distribution

The final example shown here is the assessment of contamination on the inner surface of a 30cm diameter air handling duct. This duct was used to exhaust air from a room where radioactive materials were used. The duct is a circular pipe traversing the room horizontally near the ceiling of the room. The ISOCS unit was assumed to be aimed at this duct from near the floor, at a distance of 2 meters. The radioactivity was assumed to be distributed in a thin layer around the interior surface of the duct over the 3 meter length of the duct. Table 5 shows the detection limits for this geometry, using a 60 minute measurement time. Another similar application is to evaluate residual contamination in buried pipes, e.g. drain pipes under a concrete floor or inside a concrete wall. For those nuclides with relatively high gamma energies [e.g. Cs-137, Co-60, Eu-152], covering the pipe or duct with 10cm of concrete only increases the LLD by a factor of 3-6, which is still probably acceptable from a dose standpoint for residual radioactivity.

Table 5, Detection limits for 30cm dia x 3m duct

| Nuclide | LLD uCi | LLD kBq | dpm/100 cm ² | Bq/m ² |
|-----------------|------------|------------|----------------------------|-------------------|
| Co-60 | 0.06 | 2.2 | 460 | 770 |
| Cs-137 | 0.07 | 2.5 | 540 | 900 |
| Eu-152 | 0.27 | 10 | 2200 | 3600 |
| U-238 [Th-234] | 4.3 | 160 | 34000 | 56000 |
| U-238 [Pa-234m] | 7.5 | 280 | 59000 | 100000 |
| U-235 | 0.16 | 5.8 | 1300 | 2100 |
| Am-241 | 2.6 | 94 | 20000 | 34000 |

Counting time = 60 minutes
40% coaxial Ge detector at 2 meter with no shield
Radioactivity distributed on the interior surface

MATHEMATICAL CALIBRATION METHODOLOGY

In order to use the acquired pulse height spectrum for quantitative assessment of radioactivity, an efficiency calibration must be performed. This is normally done with the use of known quantities of radioactive materials. Previous techniques that Canberra has used² [uniform mixtures of radionuclides, large numbers of small sources in inert matrices] are very expensive. The user must purchase radioactive sources of the proper range of activity and energy, distribute the source appropriately, and finally dispose the source as radioactive waste. Several years ago, Canberra began using mathematical tools for these calibrations, most successfully with MCNP^{3,4} [Monte Carlo Neutron-Particle]. When properly applied, MCNP is very accurate, of the order of 5% for well characterized sources and detectors. But MCNP is tedious to enter the descriptions necessary for the mathematical model of the source, and is VERY slow. Even with fast 64 bit 300 MHz computers, and special biasing procedures, these efficiencies can take days to compute. This is not very practical for a field instrument where a very wide range of samples are likely to be encountered.

Many previous attempts at simplified mathematical calibrations have had accuracy shortcomings due to assumptions that the detector was a point detector, and due to limitations in sample shapes. With ISOCS, however, each individual detector has a unique set of characteristics that are used to generate the calibration data. This allows all Canberra Ge detector types [Coaxial, REGe, LEGe, or XIRa] to be used, and allows any size or shape detector to be used. To ensure the maximum accuracy, each individual detector is first characterized by Canberra, at the factory, before it is delivered. The results of that indi-

vidual detector characterization are delivered to the customer as a part of the calibration software. Multiple detectors can be characterized and loaded into the software for selection by the customer. MCNP is used by Canberra for this characterization process. To accurately represent the Ge detector response, the MCNP model must be rather complex, and typically requires approximately 25 different physical elements. The output of the detector characterization process is a series of equations that defines the detector response:

- At any distance from the endcap, from 0 to 50 meter;
- At any energy from 50 - 7000 keV;
- And at any angle in all 4- π directions.

When the ISOCS user wants to do a calibration, it is a simple process taking only a few minutes. First, a template resembling the generic sample shape is chosen. Nine such templates are available:

- Simple box [basic box from point size up to many m³]
- Complex box [allows various non-uniform source distributions]
- Simple cylinder [basic drum from point size up to many m³]
- Complex cylinder [allows various non-uniform source distributions]
- Circular stacked planes [cylinders viewed from end, and for *in-situ* soil distributions]
- Rectangular stacked planes [walls, floors, ceilings]
- Pipes or ducts [source inside pipe in various locations]
- Marinelli beaker or well [detector surrounded by pipe with source on outside]
- Sphere [basic object with internal source as volume or shell]

Each of these basic shapes has many parameters that can be used where necessary to create many variations. After selecting the template, the various critical parameters that define the sample-detector geometry are measured [or estimated] and entered. These parameters include physical dimensions, material compositions, and density. Figure 4 shows the data entry screen for a 200 liter drum, and the resultant energy-efficiency curve.

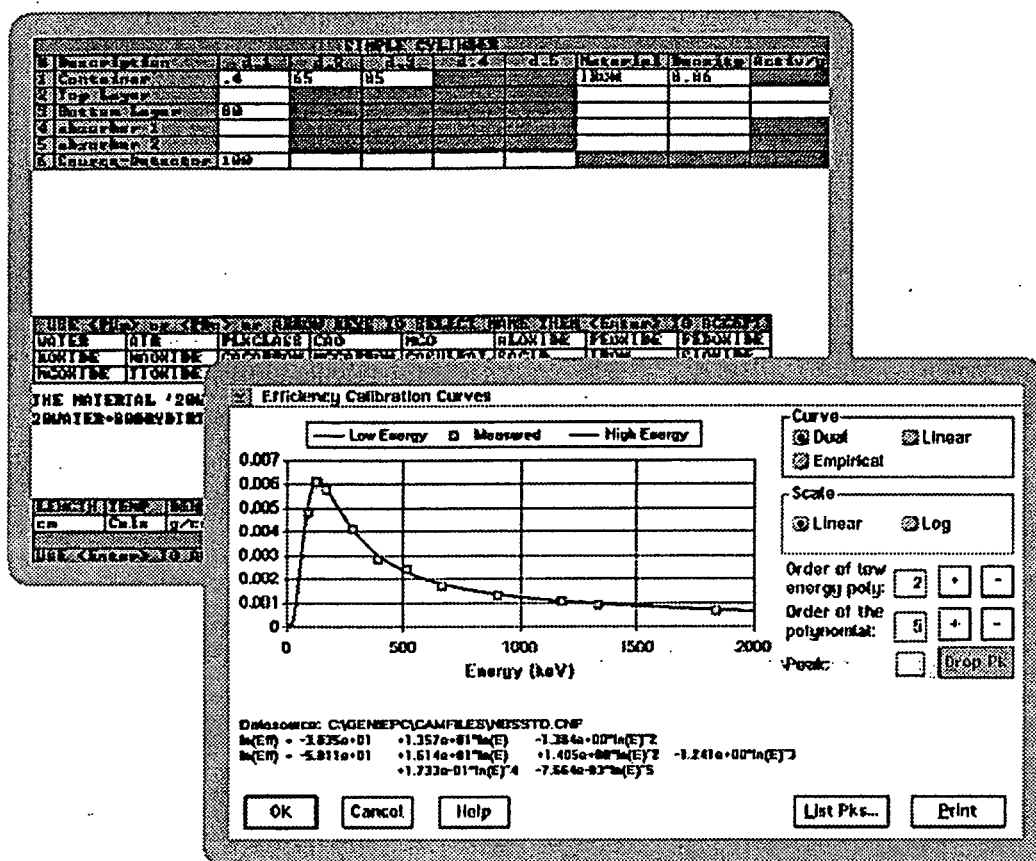


Figure 4.
A typical data entry to compute the efficiency for a 200 L drum.

If the detector is using collimation, then another series of parameters must be entered to define it. However, if the user has selected one of the ISOCS shield combinations, then a single software selection from a list deposits all the parameters into the proper location.

The composition and density of all materials must be defined so that the proper attenuation corrections can be made. This applies to the sample matrix, the sample container, any shielding and/or collimators, and the intervening air between the sample and the detector. The ISOCS materials library contains the full cross-sections of all chemical elements. Also included is a set of common materials [concrete, sand, dirt, wood, water, plastics, etc.]. It is a simple task for the user to create additional materials for addition to the library. The materials editor allows materials to be defined by entry of the chemical formula, by entry of the percentage of each element, or by fractional combinations of previously defined materials.

Finally, the relationship between the detector and the sample must be defined. Normally, this is just the distance between the detector and the sample. For ease in use, one rectangular coordinate system is used for the sample, and another one for the detector. Several other dimensions are available for entry when the object is not on the axis of the detector, and when the detector is not pointing directly at the center of the object.

After this information is entered, the user instructs the ISOCS program to compute the efficiency vs. energy datapoints. During this process, the following happens:

1. The geometric source and detector geometry information are checked for completeness, and correctness. Testing is performed for illogical dimensions and values outside the calibration range.
2. The source portion of the sample is subdivided into 1024 equal sized volume elements.

3. A point source is placed in each of these voxels. The location of this source is determined by a quasi-random process.
4. The efficiency of the first point source and at the first energy point is determined by evaluation of the detector characterization equations.
5. The pathway from that point source to the detector is examined and the path length of each absorber is computed. Air is assumed to be present in all void spaces.
6. The attenuated efficiency for that point and for that energy is computed by using the materials cross-sections for each of the absorbers. Attenuation for air is computed based upon entries for temperature, barometric pressure, and relative humidity.
7. If a collimator is present, the collimator attenuation factor is computed by examining a series of possible pathways from that point to all surfaces of the detector, and computing the effective collimator attenuation factor for that voxel point.
8. Steps 4-7 are repeated for each of the 1024 voxels. The efficiencies for all the voxels are added together.
9. Steps 2-8 are repeated for each additional source element [an object may have as many as 10 different source regions]. All the efficiencies are added together for all sources, proportional to the entered relative concentration.
10. Steps 2-9 are repeated, but this time for 2048 voxels. The difference between the two is computed. If this difference is large [compared to a user adjustable parameter], [but commonly 1%] then steps 2-8 are repeated with 4086 voxels and this result is compared with the 2048 voxel result. This process continues until convergence is satisfactorily reached.
11. Steps 2-11 are repeated, for each of the energies defined by the user for this efficiency computation.

This process takes from 5-30 seconds [normally], but could range up to 10-30 minutes or longer for combinations of large sources, multiple sources, collimators with narrow field of view, and slow computers. The output of the ISOCS process is a set of energy/efficiency/error triplets. Upon exiting the ISOCS user interface, this data is converted into the GeniePC

energy-efficiency curve format and is displayed for the user as shown in the lower section of Figure 4. Note, that at this point, the data is presented and stored just as it would be if the user had prepared a multiple energy calibration source in the appropriate geometry, counted it, analyzed the spectrum, and computed the efficiency based upon the data in the calibration source certificate file. The user now manipulates the standard GeniePC efficiency curve fitting parameters to determine the best equation that represents the energy vs. efficiency function. After the user is happy, then this is stored as an efficiency file, and is available for reanalysis of previous spectra or for newly acquired spectra.

Extensive validation of this efficiency calibration software has already been done, and will be the subject of a future report. First a series of replication tests was done. This tested the ability of the ISOCS software to generate identical results with various methods of defining the same geometry. For example, a cylindrical source can be created with the simple drum template, the complex drum template, and the pipe template. All should give the same result. A series of approximately 50 tests was done this way. All agreed satisfactorily, eventually.

Next, a series of comparisons was made between ISOCS efficiency and a reference efficiency. Although it is desirable to use traceable radioactive standards for these comparisons, that is very difficult, for the same reasons that it is difficult for us and the users to make them. They are expensive, and unless made very carefully, not very accurate. Where possible, we are using traceable sources for comparison. But, most of the difficult validations will be by comparison to MCNP computations for identical objects. MCNP has been shown ⁴ to be capable of accuracy of 5-10% or better, when properly applied.

Several hundred such tests against MCNP computations and multiple nuclide radioactive source measurements are planned, and about 2/3 are completed now. Early results showed that there were some problems in implementation [a.k.a. bugs], and also a few fundamental problems in conceptualization. Major rewriting of the program was done to increase the accuracy of the attenuation coefficient interpolation, to better handle the complex geometry when the detector is not pointed at the center of the sample, to better handle collimators, to better handle very large objects, and to correctly compute angular attenuation from sources not in front of the detector.

The accuracy of the ISOCS efficiency computation method appears to be nearly as good as the full MCNP computation for common and simple geometries. It can never be better, of course, since MCNP is used for the fundamental detector characterizations. The data analysis of the large series of validation tests is incomplete but Table 6 summarizes the current expectations.

Table 6, Accuracy of the ISOCS efficiency computations

| Measurement conditions | Expected accuracy |
|---|-------------------|
| Normal conditions, i.e. moderate to large sources, energies >150 keV | 5-10% |
| Normal conditions but energies <150 keV | 10-20% |
| Very small sources | 10-20% |
| Shielded sources [1% transmission] | 10-20% |
| Heavily shielded sources [0.01% transmission] | 50% |
| Collimators that allow most of the detector to see most of the sample | 10-30% |
| Collimators with very small holes used to measure large sources | factor of 2 |

The ISOCS accuracy is expected to be more than adequate for field measurements where the primary use of the instrument is expected. And, in our experience from the construction of these large radioactive calibration sources, the ISOCS calibrations probably are more accurate than what can be obtained by traditional source-based calibrations. And finally, for calibration of low efficiency geometries, like at large distances or with heavy collimation, the use of source based calibrations isn't practical at all, due to personnel dose considerations.

Improvements are already underway to improve the calibration accuracy, especially for laboratory sized samples. This should bring the accuracy down to the level expected by most laboratory users.

CONCLUSION

Germanium gamma spectroscopy has been shown to be a sensitive assay technique for a wide range of field assay conditions. Most common radionuclides can be measured *in situ* at sufficient accuracy for environmental level and free-release purposes. The use of *in situ* gamma spectroscopy avoids the expense of sample collection, packaging, transportation, preparation, and disposal. As a result it is generally less expen-

sive. And, because of the large sample size measured, it is also probably more accurate for non-homogeneously distributed sources than small discrete samples analyzed in the laboratory.

The ISOCS efficiency calibrations have been shown to be a quick, efficient, and accurate alternative to the traditional method of attempting to replicate the sample with multiple-energy radioactive sources. Efficiency computations can be done in minutes using data that is easily obtainable by the user. For large sample sizes encountered in field measurement situations, the ISOCS efficiency is probably more accurate than source based calibrations. For simple laboratory-sized samples containing water-equivalent samples, the use of radioactive sources is still the least expensive and most accurate method. However, when any of the following conditions are present:

- Unusual densities
- Unusual sample bulk matrix composition
- Large samples
- Samples at far distances
- Heavily attenuated samples

The ISOCS calibration method is less expensive, and quicker to do, and probably more accurate. The problem remains today, however, that mathematical calibrations, in general, are still not widely accepted, and must be well documented and proven to be acceptable to the ultimate customer and his reviewers. However, it is speculated that as the use of techniques like MCNP and ISOCS become more common and more refined, mathematical calibrations will be the preferred option a few years from now.

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- [3] Briesmeister, J. F. (ed.), November 1993, MCNP - A General Monte Carlo N-Particle Transport Code, Version 4a. Report LA-12625-M, Los Alamos National Laboratory.
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**ISOCs [IN SITU OBJECT COUNTING SYSTEM] PORTABLE GAMMA
SPECTROSCOPY INSTRUMENT**

**CHICAGO PILE 5 (CP-5) RESEARCH REACTOR
LARGE-SCALE DEMONSTRATION PROJECT**

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 **CANBERRA**

ISOCS [IN SITU OBJECT COUNTING SYSTEM] PORTABLE GAMMA SPECTROSCOPY INSTRUMENT

CHICAGO PILE 5 (CP-5) RESEARCH REACTOR LARGE-SCALE DEMONSTRATION PROJECT

SUMMARY

The objective of the Large-Scale Demonstration Project (LSDP) is to select and demonstrate potentially beneficial technologies at the Argonne National Laboratory-East (ANL) Chicago Pile-5 (CP-5) Research Reactor. The purpose of the LSDP is to demonstrate that by using innovative and improved decontamination and decommissioning (D&D) technologies, significant benefits can be achieved when compared with baseline D&D technologies. A major part of the D&D effort is the characterization of the type, extent and level of contamination. This report describes a demonstration of Canberra Industries' ISOCS [In Situ Object Counting System] instrument for assessing gamma emitting contaminants in and/or on various sized and shaped objects.

The ISOCS instrument consists of a germanium (HPGe) detector, adjustable shield and collimator, equipment cart, portable multi-channel analyzer (MCA), laptop computer and special efficiency calibration software. The system may be taken into the field, used to count and analyze samples, identify radionuclides and provide immediate results. The more common method of collecting samples for laboratory analysis is expensive, time consuming, may add to personnel exposures and can be unreliable, especially if the distribution of the contamination is non-uniform. *In situ* measurements can reduce these problems, be performed at lower cost, and produce results nearly instantaneously. The traditional problem of constructing calibration sources for each object to be counted is eliminated by use of the ISOCS mathematical efficiency calibration process, which can be performed in the field, if needed.

In situ measurements were performed at several locations within the CP-5 Research Reactor and at locations in accelerator and hot cell facilities. Objects which were assayed included contaminated concrete floors, contaminated concrete walls, fuel pool walls, waste storage containers, activated

accelerator components and miscellaneous activated pieces. Quantitative and qualitative results were derived using the ISOCS efficiencies and Genie-PC analysis.

TECHNOLOGY DESCRIPTION

ISOCS is a portable gamma spectroscopy instrument designed to identify and quantify gamma-emitting radionuclides in various sized and shaped objects in the field.

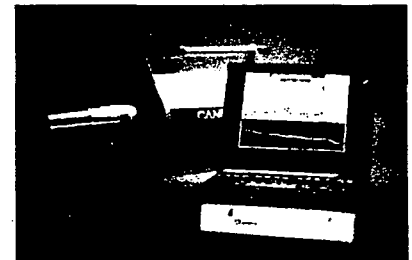


Figure 1. Detector, InSpector, MCA, and Portable Computer

The instrument consists of the following components:

- HPGe detector of the appropriate type, size, and shape for the application.
- A Multi-Attitude Cryostat to allow the detector to be pointed in any direction.
- Sets of 25mm and 50mm shields, each with various angle collimators, to define the field of view of the HPGe detector and to reduce interference from other sources.
- A cart to move the equipment, mount the detector, and to point it at the object to be measured.
- The InSpector, a portable electronics package that includes the High Voltage Power Supply, amplifier, Analog-to-Digital Converter and Multi-Channel Analyzer.
- Portable laptop computer for sample information input, InSpector control, and data acquisition, analysis and storage.
- GeniePC Gamma Spectroscopy software for spectral analysis and nuclide identification.

- ISOCS Efficiency Calibration software to allow the user to derive efficiencies for objects being counted.

Initial start-up requires about four hours for detector cool down and assembly of the cart and detector mounting components. Thereafter, the system can be moved from location to location, set up and operated within a few minutes. Efficiencies for the objects to be assayed may be generated prior to, or after, field measurements, or while data are being collected as described below. Following completion of counting, data are analyzed and stored. Results may be viewed in the field within two minutes of completion of counting.

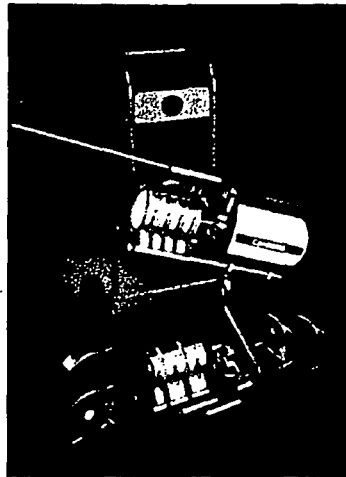


Figure 2. ISOCS Shield and Detector

The ISOCS mathematical efficiency calibration routine produces a unique calibration for each detector, using that detector's specific characteristics. The software provides a set of nine generic object templates which include boxes, cylinders, circular and rectangular stacked planes, pipes, spheres, and wells. Each template has many parameters that can be used to create variations that best represent the object to be counted. The process is quick and simple. The user selects the appropriate template, detector, and collimator to be used. Parameters, such as material composition and density, and source distribution, are entered and the efficiency vs. energy curve calculated. This process may take from one minute for simple geometries to 10 minutes for more complex configurations. The curve is stored in the appropriate GeniePC file for use when analyzing spectra. The ISOCS efficiency software has been validated with constructed standards and with MCNP (Monte Carlo Neutron Photon Transport Code) calculations.

DEMONSTRATION PERFORMANCE

The purpose of the project measurements was to

demonstrate the value of the instrument for performing high quality *in situ* gamma spectroscopy. The advantages of *in situ* measurements over the more traditional combination of gross measurements and sampling, followed by laboratory analysis (baseline technologies) include:

- Identification of nuclide specific contaminants.
- Reduction of large potential errors from non-homogeneous source distributions.
- Reduction of cost associated with sampling and laboratory analyses.
- Elimination of time delays between sampling and analysis results.
- Improved safety by elimination of sampling in hazardous conditions.
- Derivation of total activity and average concentrations in difficult to sample objects.

Measurements were made at several locations within the CP-5 Research Reactor, at a deactivated accelerator facility, and at a hot cell facility where D&D is scheduled. In each case, the task was to identify the contaminants present and to obtain an estimate of the level of contamination in, or on, the objects using the ISOCS efficiency calibration software for quantitative determinations. At CP-5, the ISOCS assessment of floor contamination may be compared to measurements made with gross activity instruments, such as beta detection systems (GM tubes or gas proportional counters), or with gamma counting using NaI(Tl) detectors. These gross measurements, however, are not reliably quantitative, as many uncertainties exist in determining the nuclide and distribution and, therefore, the efficiency. Because these areas are difficult and unreliable to sample for laboratory measurement, no other quantitative comparisons are available.

Over a period of approximately two work days, a total of 28 *in situ* measurements were completed at the three different facilities. Whenever possible, the *in situ* results are compared to gross surface activity measurements. Gross measurements are typically made with beta detecting devices which, for ease and durability of source preparation, have been calibrated with beta emitting nuclides such as Sr-90 deposited on smooth metal or plastic surfaces. These common calibration sources, however, rarely represent actual counting geometries.

In addition, gross activity meters are used in a scanning mode and require sufficient time over relatively small measurement locations for complete detector response. These characteristics should be compared to ISOCS measurements which are nuclide specific, average readings over larger areas, and can account for geometry problems such as absorption and/or attenuation of photons.

Due to the limited time allocated for site measurements, the ISOCS system was configured for basic *in situ* measurements. Improvement in the quality of results can be obtained by the use of different assay strategies for specific conditions. For example, measurements of activity in the shielded cask could be improved by taking readings from different angles and distances. This was not possible during the demonstration due to restrictions placed on movement because of radiological conditions. Measurements taken in elevated background locations could be better corrected by collecting a set of completely shielded acquisitions at critical locations for background subtraction. Again, not possible during the demonstration due to the schedule. For nuclides with multiple energy photopeaks, actual depth of contamination can be derived from the ratio of peaks (i.e. differential peak absorption). Nuclides of this type were not present at CP-5. Depth may also be evaluated by acquiring several spectra of the object from different directions. All of these techniques, while not employed for this study, are available to refine and enhance results.

RESULTS

The project results are shown below for each measurement location. Included is a description of the geometry, nuclide identification, and activity result. One sigma counting errors are reported with each result. Other errors associated with geometries and efficiencies may range from a few percent to values estimated at +/- 50%, depending upon how well the selected efficiency geometries represent actual configurations. When alternate geometries were analyzed, results are reported.

CP501: Measurement of surface contamination in the truck dock area of the CP-5 facility.

The contamination is on a concrete surface, covered with herculite to prevent the spread of loose contamination, extending over an area of

about five meters by nine meters. Contamination is known to be non-uniform with elevated hot spots in one quarter of the area. This acquisition was performed with the detector centered in the contaminated area at a height of one meter with 25mm thick shielding and 180 degree collimation. The objective of this measurement was to obtain a total surface activity and average contamination level over the entire contaminated area. Contamination levels, as measured with a beta sensitive gas proportional counter, ranged from 20,000 to 320,000 dpm/100 cm².

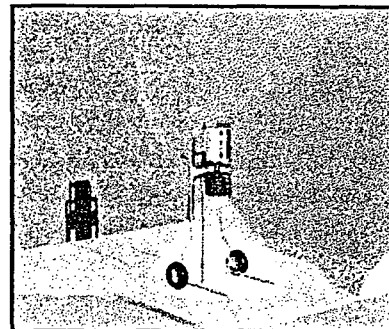
CP501: ISOCS Reported Results

| | |
|--------|--------------------------------------|
| Cs-137 | 4.9 E5 dpm/100cm ² +/- 3% |
| Co-60 | 1.1 E3 dpm/100cm ² +/- 4% |

The efficiency used was for a rectangular plane with an assumed contamination layer of 0.5cm in concrete. Although the actual depth of contamination is not known, this is not a very sensitive calibration factor. If, instead of a depth of 0.5cm, the contamination is assumed to be 1.0cm or 0.1cm, the results only vary by less than 10%. The contamination level for Cs-137 for an assumed 1.0cm layer is 530,000 dpm/100cm², and for a 0.1cm layer is 455,000 dpm/100cm².

CP502: Measurement of surface contamination in the truck dock area of the CP-5 facility.

The contamination is on a concrete floor, covered with herculite to prevent the spread of loose contamination. The detector was placed in the approximate center of the



quadrant containing the highest levels of contamination at one meter and collimated with the 25mm, 30 degree collimator in an effort to focus on the elevated areas. Contaminations levels, as measured with a gas proportional counter, averaged 300,000 dpm/100cm².

CP502: ISOCS Reported Results

| | |
|--------|--------------------------------------|
| Cs-137 | 2.9 E6 dpm/100cm ² +/- 3% |
| Co-60 | 2.2 E4 dpm/100cm ² +/- 3% |

The efficiency employed was a circular plane, 3m diameter, with activity assumed to be in a 0.5cm layer of concrete. ISOCS results higher than survey meter results may be explained by likely beta absorption in the concrete and herculite layers biasing the proportional counting results low. Argonne reported that the lab analyses were a factor of 10 higher than field surface measurements for similar surfaces at the Bldg 301 facility, a geometry similar to this location.

CP503: Measurement of surface contamination in the truck dock of the CP-5 facility.

The contamination is on a concrete floor covered with herculite to prevent the spread of any loose contamination. The detector was placed at a location midway between the highest levels and the lower levels, at a height of one meter and collimated with the 25mm, 30 degree collimator. Estimated levels from gas proportional measurements are 100,000 to 200,000 dpm/100cm².

CP503: ISOCS Reported Results

| | |
|--------|--------------------------------------|
| Cs-137 | 1.9 E0 dpm/100cm ² +/- 5% |
| Co-60 | 7.7 E3 dpm/100cm ² +/- 7% |

Efficiency was a circular plane, 3m diameter with a layer of 0.5cm concrete activity

CP504: Measurement of surface contamination in the truck dock of the CP-5 facility.

The contamination is on a concrete floor covered with herculite to prevent the spread of any loose contamination. The detector was placed over the low activity end of the contaminated area, at a

CP504: ISOCS Reported Results

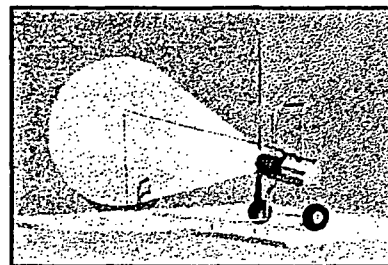
| | |
|--------|--------------------------------------|
| Cs-137 | 3.8 E5 dpm/100cm ² +/- 3% |
| Co-60 | 6.0 E3 dpm/100cm ² +/- 5% |

height of one meter, and shielded with the 25mm, 30 degree collimator. Proportional counter levels ranged from 5000 to 75,000 dpm/100cm².

Efficiency was a circular plane, 3m diameter with 0.5 cm layer of concrete activity

CP505: Measurement of surface contamination in the truck dock of the CP-5 facility.

The contamination is on a wall adjacent to the contaminated floor. The wall is concrete with an area of



contamination about 142cm x 44cm and is covered with herculite. The detector was mounted horizontally to view the wall at a distance of 130cm with the 25mm, 30 degree shield/collimator. The levels of contamination on the wall were not previously well defined.

CP505: ISOCS Reported Results

| | |
|--------|--------------------------------------|
| Cs-137 | 1.9 E6 dpm/100cm ² +/- 5% |
| Co -60 | 9.9 E4 dpm/100cm ² +/- 5% |

Efficiency was a rectangular plane the size of the wall with a 0.5 cm layer of activity in concrete.

CP506: Measurement of surface contamination in the truck dock of the CP-5 facility.

The location is the same as with CP505. The detector, however, was moved closer to the wall surface. The detector to wall distance was 43cm, with the 25mm 30 degree collimator/shield in place.

CP506: ISOCS Reported Results

| | |
|--------|--------------------------------------|
| Cs-137 | 2.6 E6 dpm/100cm ² +/- 4% |
| Co-60 | 2.2 E4 dpm/100cm ² +/- 7% |

Efficiency was for the same wall area, but at 43cm distance, rather than the 130cm distance for

CP505. Results of the two wall measurements were reasonably consistent and probably within the overall measurement errors. The peak areas for this acquisition were less than for the first, suggesting that some of the wall area was cut off by moving closer to it. The efficiency accounted for this, however.

CP507: Measurement of surface contamination in the truck dock of the CP-5 facility.

The contamination is the covered floor as described in CP501 through CP504. The detector was placed over the highest location of contamination, as with CP502, at a height of one meter, except the shield was 25mm with the 180 degree collimator. Contamination levels from proportional counter measurements were 200,000 to 300,000 dpm/100 cm² near the detector.

CP507: ISOCS Reported Results

| | |
|--------|--------------------------------------|
| Cs-137 | 2.7 E6 dpm/100cm ² +/- 4% |
| Co-60 | 1.3 E4 dpm/100cm ² +/- 4% |

Efficiency was for the rectangular plane area with a 0.5cm concrete layer of activity, with 180 degree collimator. Average levels for the entire area would be biased high by the elevated readings directly beneath the detector.

CP508: Measurement of surface contamination in the truck dock of the CP-5 facility.

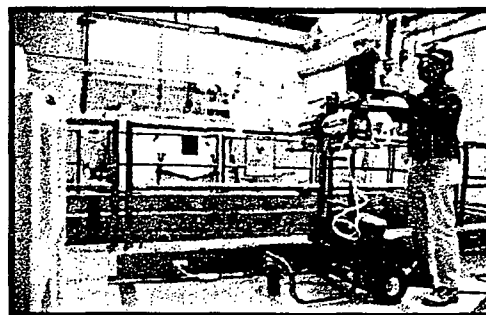
The surface is the covered floor as described in CP501 through CP504. The detector was placed over the location of lowest contamination, as in CP504, except that the shield was the 25mm with the 180 degree collimator. Detector height was one meter.

CP508: ISOCS Reported Results

| | |
|--------|--------------------------------------|
| Cs-137 | 8.9 E4 dpm/100cm ² +/- 3% |
|--------|--------------------------------------|

Efficiency was for the rectangular plane area with 0.5cm concrete layer and 180 degree collimator.

CP509: Assessment of activity in waste containers in the fuel pool area of the CP-5 facility.



The activity is contained in four 55-gallon drums stored in a shielded cask. Measurements were made from across the fuel pool, at a distance of 4m, with the detector shielded with the 25mm, 30 degree collimator. The cask is 8 ft diameter by 5 ft high, and has a wall thickness of 2 inches of lead. External dose rates are 5 mR/hr at 6 ft from the cask. The highest level drum is located in the center of the cask.

CP509: ISOCS Reported Results

| | |
|--------|-----------------|
| Co-60 | 0.18 Ci +/- 3% |
| Cs-137 | 0.03 Ci +/- 10% |

Efficiency was for a pipe source, to simulate the 55-gallon drum in the center of the cask, with an attenuator of 2 inches Pb. The activity was assumed to be distributed throughout the drum, although, at that distance, the source geometry probably did not make much difference. As an approximate confirmation of this activity, calculations show that a 0.2Ci Co-60 source attenuated by 2 inches of Pb, would yield an exposure rate of about 4 mR/hr at a distance of 2m (with build-up). This exposure rate is consistent with those measured around the cask.

CP510: Measurement of surface contamination in the fuel pool area of the CP-5 facility.

The activity is on the surface of the fuel pool walls, which are concrete covered with SS. The measurement location was at the midpoint of the pool length at the top opposite the fuel cask. The detector was shielded with the 25mm, 30 degree

collimator and pointed down the opposite wall such that the center line of the detector was aimed 3 feet below the top of the fuel pool wall. There are no other measurements for these walls.

CP510: ISOCS Reported Results

| | |
|--------|---------------------------------------|
| Co-60 | 5.3 E5 dpm/100cm ² +/- 3% |
| Cs-137 | 3.5 E4 dpm/100cm ² +/- 27% |

Efficiency was for a large surface area of about 3 E5cm², at a distance of 3.3m from the detector. Subsequent calculations and efficiency runs have shown that the collimator did not effectively shield the storage cask and, in fact, the detector had a clear view of part of the cask. Therefore, these readings are known to be biased high due to contribution from the cask activity. This was anticipated as a possibility and additional measurements were taken as described below.

CP511: Measurement of surface contamination in the fuel pool area of the CP-5 facility.

The measurement is at the same location as CP510, except that the detector was shielded with the 50mm, 30 degree collimator, and was pointed (angled) further down the opposite wall in an effort to obtain better shielding of the storage cask at the top of the pool. The center line of the detector was aimed 3m below the top of the fuel pool wall.

CP511: ISOCS Reported Results

| | |
|-------|--------------------------------------|
| Co-60 | 1.5 E5 dpm/100cm ² +/- 3% |
|-------|--------------------------------------|

Efficiency is for a large surface area approximately 7 E5cm², at a distance of 4.2m from the detector. This geometry has been shown to provide shielding from all direct outside sources such as the cask. However, some penetration of the collimator is possible for high energy photons such as those from Co-60, and a contribution from the storage cask via penetration of the collimator is possible. This contribution can be estimated by counting with a completely shielded detector, which was not

performed at CP-5 due to time limitations, or by calibrating for the shielded drum even though it is shielded by the collimator, and correcting for the interference.

CP512: Measurement of surface contamination in the fuel pool area of the CP-5 facility.

The contamination is on the fuel pool walls. The measurement location is opposite that for CP510 and CP511 (i.e. from the side where the storage cask is located, but behind a concrete shield to prevent contribution from the cask). The detector is located near the end of the pool length, shielded with the 50mm, 90 degree collimator, and pointed with a center line 10ft below the top of the fuel pool.

CP512: ISOCS Reported Results

| | |
|--------|---------------------------------------|
| Co-60 | 2.2 E4 dpm/100cm ² +/- 10% |
| Cs-137 | 9.0 E3 dpm/100cm ² +/- 6% |

Efficiency was for a surface area, 5 E5 cm², as above. This is the optimum shielded geometry, probably gives the best results for the fuel pool walls, and suggests that much of the CP511 result was from shield leakage.

CP513: Measurement of surface contamination in the fuel pool area of the CP-5 facility.

The contamination is on the fuel pool walls. The measurement location is from the end of the fuel pool, viewing the opposite end and floor of the pool, with the detector center line near the bottom of the pool wall at the floor. The detector was shielded with the 50 mm, 90 degree collimator.

CP513: ISOCS Reported Results

| | |
|--------|--------------------------------------|
| Co-60 | 6.8 E4 dpm/100cm ² +/- 3% |
| Cs-137 | 3.0 E4 dpm/100cm ² +/- 8% |

Efficiency was for a large rectangular plane. This geometry was difficult to estimate, in terms of area viewed, due to the angular planes of the floor and walls. The results should be considered gross estimates only.

ACC01: Measurement of activation activity at an accelerator facility.



The activity is contained in a set of accelerator "Dees" which have been inactive for several years. The Dees are metal blocks 130cm by 46cm in area, with a depth of about 30cm. The activity is known to be contained within these components as a result of activation from accelerator particles, but the depth and/or location is unknown. The detector was set at a distance of 240cm with the 25mm, 90 degree collimator. Exposure rates near the Dees were 200 uR/hr, and not high enough to find any hot spots or elevated areas.

ISOCS Reported Results

ACC01: Geometry 1 - 30cm depth

| | |
|-------|----------------------|
| Na-22 | 1.2 E1 pCi/g +/- 25% |
| Mn-54 | 3.8 E2 pCi/g +/- 3% |
| Co-60 | 4.1 E3 pCi/g +/- 3% |
| Zn-65 | 5.1 E2 pCi/g +/- 4% |

ACC01: Geometry 2 - 5cm depth

| | |
|-------|----------------------|
| Na-22 | 1.4 E1 pCi/g +/- 28% |
| Mn-54 | 4.2 E2 pCi/g +/- 3% |
| Co-60 | 4.8 E3 pCi/g +/- 2% |
| Zn-65 | 5.8 E2 pCi/g +/- 4% |

Quantitative results depend on the assumptions made concerning the volume of the Dees that are activated. Two geometries were tested - one assuming the entire volume is activated, and the second assuming a 5cm depth of activation. The source geometry was a rectangle block of SS with a thickness of source (activation layer) of 30cm or

5cm. The results show similar concentrations for each geometry, although total source volume and activity would be different. Unfortunately, there was insufficient activity to allow for analysis of multiple lines to determine which activation depth is most appropriate.

ACC02: Measurement of activated components at an accelerator facility.

The activity is in the form of activated components and parts which have been stored in 5-gallon pails as waste for disposal. The detector was placed 188cm from the pail and shielded with the 25mm, 30 degree collimator.

ACC02: ISOCS Reported Results

| | |
|-------|---------------------|
| Na-22 | 8.7 E1 pCi/g +/- 1% |
| Co-60 | 1.1 E3 pCi/g +/- 4% |

Efficiency was a pipe simulating a 5-gallon pail filled with SS components. Since the pail was not solid SS, the density was adjusted to account for empty space in the pail. These changes made some differences in the final numbers (i.e. +/- 40%).

ACC03: Measurement of activation activity at an accelerator facility.

Measurement of the activated Dees, as ACC01, except that the detector distance is 188cm and the angle is slightly different.

ACC03: ISOCS Reported Results

| | |
|--------|----------------------|
| Na-22 | 1.2 E2 pCi/g +/- 4% |
| Mn-54 | 5.1 E1 pCi/g +/- 2% |
| Co-60 | 3.3 E3 pCi/g +/- 2% |
| Zn-65 | 7.4 E1 pCi/g +/- 14% |
| Cs-137 | 8.0 E1 pCi/g +/- 9% |

Efficiency was the 5cm activation depth in a rectangular block of SS. Results are similar to those from ACC01

ACC04: Measurement of activation activity at an accelerator facility.

Same as ACC01 and ACC03 except that the angle is different and the distance is 193cm.

ACC04: ISOCS Reported Results

| | |
|-------|----------------------|
| Na-22 | 2.0 E1 pCi/g +/- 40% |
| Mn-54 | 2.7 E1 pCi/g +/- 22% |
| Co-60 | 3.7 E3 pCi/g +/- 2% |
| Zn-65 | 1.7 E2 pCi/g +/- 9% |

Efficiency was the same as with ACC01 and ACC03, with similar results.

ACC05: Measurement of activated components at an accelerator facility.

Measurement of stainless steel cannisters containing charcoal. Cannisters are 53cm tall by 15cm diameter, with two side-by-side. The detector was placed at a distance of 75 cm and was shielded with the 50mm, 90 degree collimator. There were low count rates with hand-held survey instruments at contact with the columns.

ACC05: ISOCS Reported Results

| | |
|-------|---------------------|
| Co-60 | 9.0 E2 pCi/g +/- 2% |
|-------|---------------------|

Efficiency was a pipe geometry with a SS casing and charcoal interior, uniform activity. Following this assay, the column was removed and a background counted at this location, with an activity equal to 10% of the column activity reported.

ACC06: Measurement of activated components at an accelerator facility.

Activity is assumed to be on the surface of a vacuum pump assembly, possibly the meter faces. The assembly is 69cm x 61cm x 61cm. The detector was positioned 68cm from the meter faces with the 50mm, 90 degree collimator. There were low count rates with hand-held instruments on the face.

ACC06: ISOCS Reported Results

| | |
|--------|--|
| Co-60 | 2.8 E6 dpm/100cm ² +/- 4% |
| Eu-152 | 2.0 E3 dpm/100 cm ² +/- 11% |

Efficiency was a rectangle plane with surface contamination/activation. The background for this item was similar to that for ACC05 and was equivalent to the estimated surface contamination. Therefore, it is concluded that activity on the meter faces is below the detection limits of the *in situ* system.

30101: Measurement of surface contamination at a hot cell facility.

The contamination is on a concrete floor which has been painted to fix removable contamination. The location is in the back room behind the hot cells, where floor contamination is general and somewhat uniform. The detector was set at one meter with the 25mm, 30 degree collimator. Levels with hand-held beta-gamma (GM tube) detectors averaged about 6000 dpm/100cm².

30101: ISOCS Reported Results

| | |
|--------|---------------------------------------|
| Cs-137 | 7.9 E4 dpm/100 cm ² +/- 3% |
|--------|---------------------------------------|

Efficiency was a circular plane, 3m diameter, with 0.5cm concrete layer of concrete activity. At this facility, Argonne reported the ratio of laboratory analysis to survey meter readings to be 10:1. This is consistent with ISOCS results.

30102: Measurement of activity on a smear in the hot cell facility.

The smear was mounted 4cm from the face of the detector and counted for total activity. Survey meter readings for the smear were 45,000 cpm alpha and 4000 cpm gamma with a scintillation detector.

30102: ISOCS Reported Results

| | |
|--------|----------------------------------|
| Cs-137 | 5.5 E-4 uCi (20,000 dpm) +/- 13% |
|--------|----------------------------------|

Efficiency was a circular plane, cellulose, surface activity. If the scintillation detector is 10% efficient for Cs-137 gammas, the *in situ* results would be consistent within the uncertainties of the measurement geometries (possibly +/- 50%).

30103: Measurement of surface contamination at an accelerator facility.

The contamination was a hot spot on the floor, painted over, near the entrance to Cave No. 4A. The detector was at one meter with the 50mm, 30 degree collimator and the hot spot is about 35cm diameter. Results of survey meter readings were "175k" and "280k" cpm at hot spot locations (written on the floor). It is assumed these are beta-gamma readings.

30103: ISOCS Reported Results

Cs-137 4.4 E4 dpm/100cm² +/- 5%

Efficiency was a circular plane with 0.5cm concrete layer activity. The hot spots, as measured with survey meters, were probably higher than *in situ* results, possibly 1-2 E6 dpm/100 cm² depending on the area of the probes. ISOCS averaged these hot spots over the entire area viewed.

30104: Measurement of surface contamination at an accelerator facility.

The measurement is the same as 30103, except that the detector was lowered to a height of 56cm., with the 50mm, 30 degree shield, and centered over the 200k cpm hot spot.

30104: ISOCS Reported Results

Cs-137 1.1 E6 dpm/100cm² +/- 5%

Efficiency was a circular plane 600cm² (area of the hot spot) with 0.5cm concrete layer of activity. Results are closer to survey meter readings because the elevated readings are averaged over smaller areas.

30105: Measurement of surface contamination at an accelerator facility.

The contamination is a hot spot on the floor adjacent to the Cave No. 4A door. The spot is approximately 20cm in diameter. The detector was placed at a height of 56cm, with the 50mm, 30 degree shield. There were no floor readings from

survey meters.

30105: ISOCS Reported Results

Cs-137 7.7 E5 dpm/100cm² +/- 4%

30106: Measurement of activity at a hot cell facility.

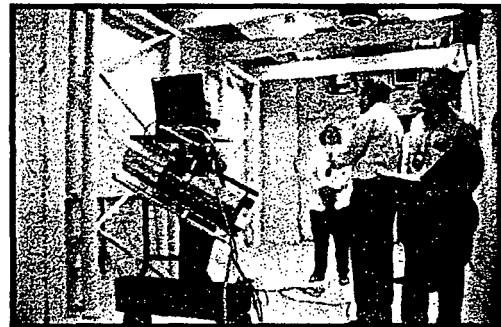
Measurement of a location of elevated dose readings (1 mR/hr) at the bottom of Cell A door. Readings may be from contamination on the floor or due to streaming from the hot cell interior. The detector was set at 183cm with the 50mm, 30 degree collimator.

There are no assessments with which the *in situ* readings may be compared.

30106: ISOCS Reported Results

Cs-137 1.0 E0 uCi +/- 10%

30107: Measurement of surface contamination at a hot cell facility.



Location is a hot spot on the wall of Cave No.3. The detector was positioned 69cm away with the 50 mm, 30 degree collimator. The spot is about 5cm diameter.

30107: ISOCS Reported Results

Cs-137 6.9 E-2 uCi +/- 9%(150,000 dpm) over the hot spot

Efficiency was a circular plane 5cm diameter.

30108: Measurement of surface contamination at a hot cell facility.

The contamination is a hot spot on the concrete floor, covered with paint, in the Clean-up Room. The spot diameter is about 33cm and reads 100 uR/hr at 1cm with a NaI(Tl) microR meter. The detector was at 1m, with the 50 mm, 30 degree collimator.

30108: ISOCS Reported Results

| | |
|--------|--------------------------------------|
| Cs-137 | 2.3 E6 dpm/100cm ² +/- 3% |
|--------|--------------------------------------|

Efficiency was a circular plane 33cm dia with 0.5cm concrete activity. Comparison with exposure rate readings near a planar source are difficult.

30109: Measurement of surface contamination at a hot cell facility.

The contamination is on the floor, covered with paint, in the front cell area. General levels are low - near MDA for hand-held instruments. The detector was at 1m, with the 50 mm, 30 degree collimator.

30109: ISOCS Reported Results

| | |
|--------|--------------------------------|
| Cs-137 | 5.0 E2 dpm/100 cm ² |
|--------|--------------------------------|

Efficiency was a circular plane source, area 3 m², with 0.5cm concrete activity layer. This activity may be below the LLD for GM tube instruments doing scanning surveys.

CONCLUSIONS

The ISOCS system was able to provide assessments of a variety of items and components in three different radiological facilities. When alternate survey or measurement data were available and reliable, results were comparable. ISOCS was able to perform measurements at locations where access was difficult - such as along the surface of the fuel pool where workers would have to be suspended to perform manual surveys - or where

sampling is not practical - such as with the accelerator Dees.

ISOCS efficiencies can be generated at the time of acquisition or after measurements, as was the case for most of the measurements performed for this study. Spectral data may also be displayed and/or reported at the time of acquisition or viewed later. Examples of efficiency curves and spectral data are attached.

In addition to ISOCS providing accurate and reliable results in real time, the system also proved to be less expensive and time consuming than traditional sample collecting methods.

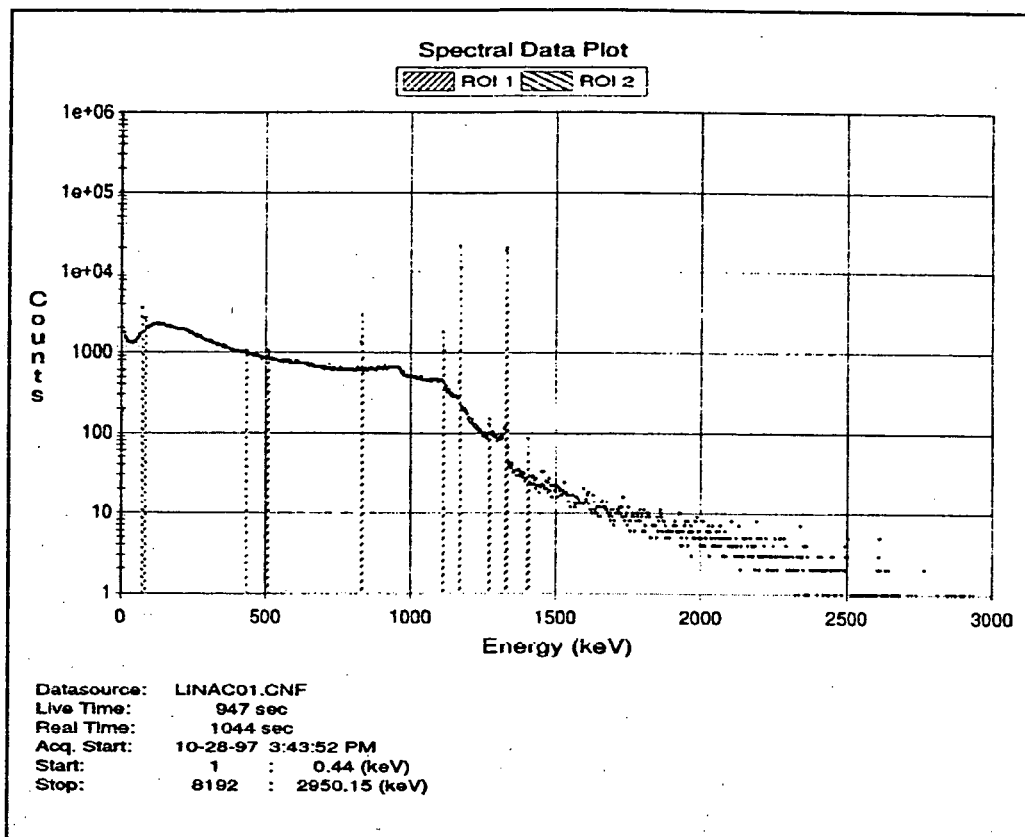


Figure 5. Spectral plot of accelerator activated components, showing Co-60, Zn-65, Mn-54, and Na-22 photopeaks.

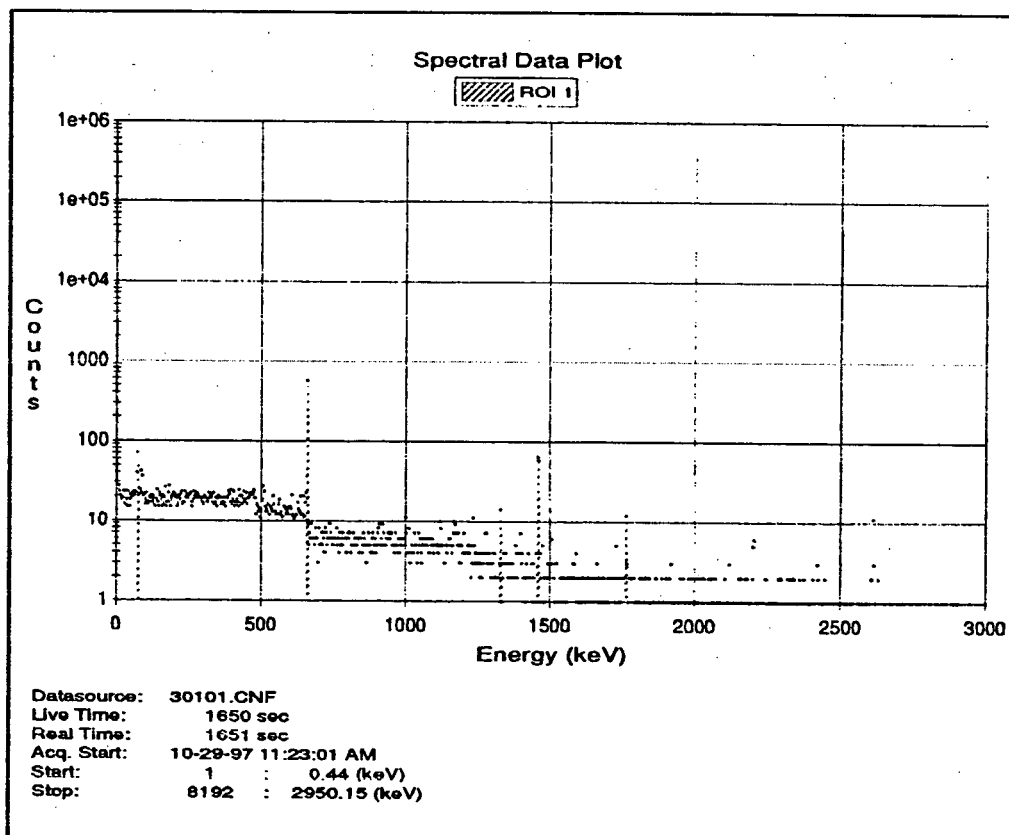


Figure 6. Spectral plot of contaminated floor in CP5 facility, showing photopeaks for Cs-137 and naturally occurring radionuclides in concrete.

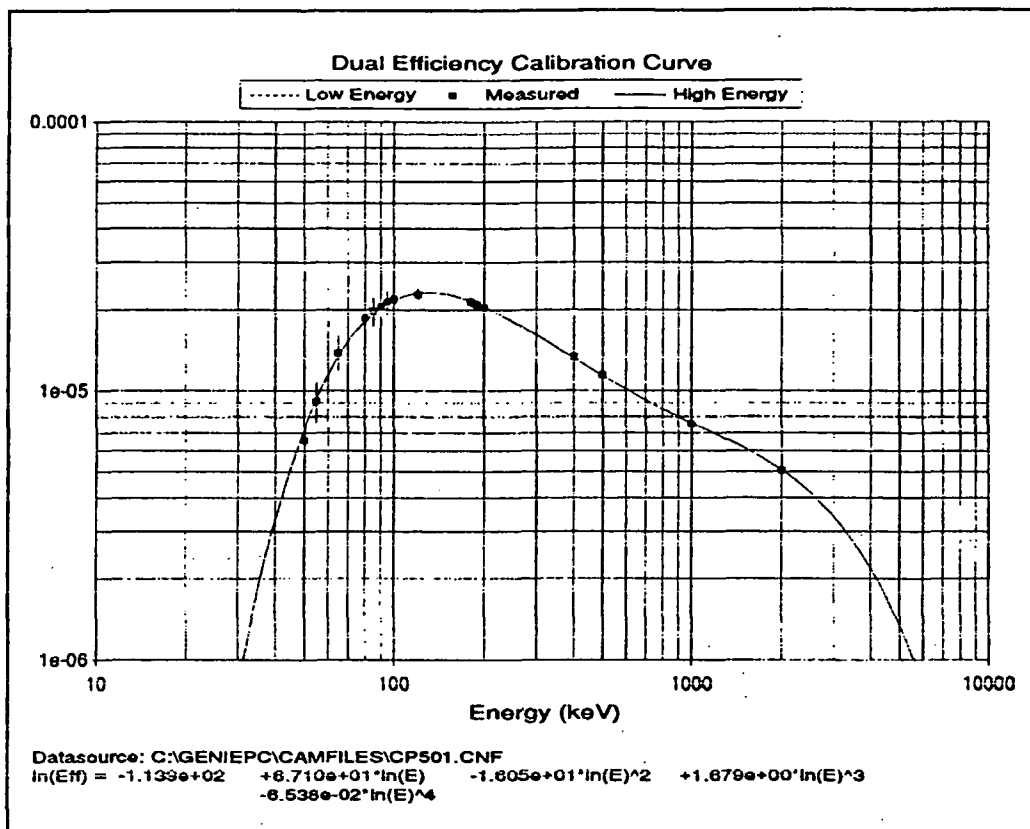


Figure 3. Plot of efficiency for a 5cm layer of contamination on the surface of a 3m² concrete circular plane (CP5 floor). Units are counts/gamma.

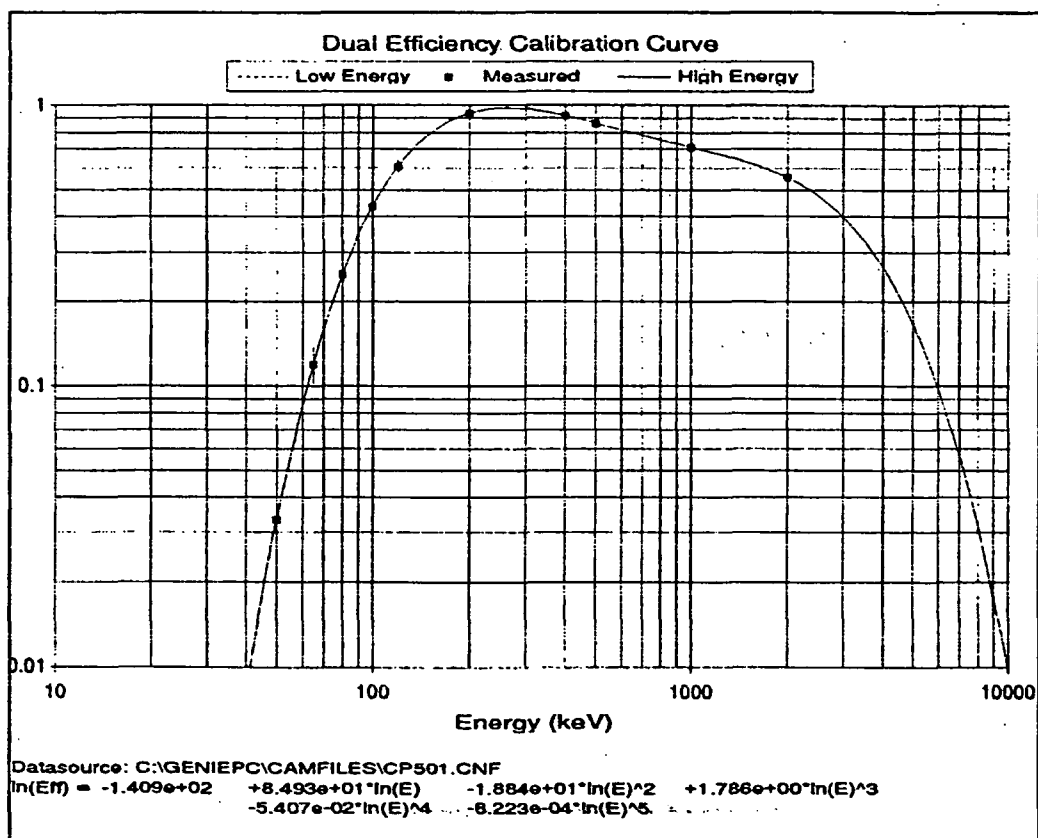


Figure 4. Plot of efficiency for a ss block with a 5cm activation depth (accelerator dees). Units are counts/gamma/gram.

VALIDATION OF *INSITU* OBJECT COUNTING SYSTEM (ISOCS) MATHEMATICAL EFFICIENCY CALIBRATION SOFTWARE

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Abstract

The ISOCS calibration method is a convenient tool for calibrating the detector efficiency as a function of energy for a wide variety of source geometries and activity distributions. The ISOCS method consists of a Canberra characterization of the detector, user input of source geometry data, and the ISOCS software which uses these to produce the efficiency calibration. During the characterization, an MCNP model of the detector is developed. The model is then independently validated using measurements with a NIST traceable source. Given the validated model, the response characteristics of the detector are mapped out to cover any location inside a sphere of radius 50 meters, centered on the detector, and over a photon energy range of 50 keV through 7 MeV. The ISOCS software contains a series of mathematical models that can simulate a wide variety of sample shapes. The software divides each source region into a number of voxels. Inside each voxel, a point location is defined in a quasi-random fashion. At a given energy, the detector efficiency is calculated for each voxel, taking into account the attenuation due to absorbers both inside and outside the source. The efficiencies for all the voxels are summed up at the given energy. To determine the accuracy of this calibration method, a large number of tests (about 109) were performed. In each of these tests, a reference efficiency calibration was compared to an ISOCS efficiency calibration at the same geometry. The reference calibration was either from a full MCNP calculation, or from a multi-energy radioactive source. The tests were categorized into 3 different counting geometries, namely, Field, Laboratory, and Collimated geometry. The data for each geometry were further divided into low energy (< 150 keV) and intermediate to high energy (> 150 keV) groups. The mean ratio of ISOCS/True efficiencies was (i) 1.01 ± 0.007 for the Field geometries, (ii) 0.97 ± 0.007 for the Laboratory geometries, and (iii) 1.09 ± 0.014 for the Collimated geometries. By analyzing the relative uncertainties in the True efficiencies, and the relative standard deviation in the ratios, the average relative standard deviation due to ISOCS is estimated to be 6.5%, 5.4%, and 10.5%, for the Field, Laboratory, and Collimated geometries, respectively. Various sources of bias affecting the data have been identified from this validation process. Improvements have been made in the characterization process and in the algorithms, which will be implemented in future versions of the ISOCS efficiency calibration software.

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1. Introduction

In environmental and other in situ applications, the objects to be assayed are, frequently, large in size. If gamma spectroscopy is to be used in the assay, the detector efficiency has to be calibrated as a function of energy for such large objects. Construction of laboratory sized calibration standards is relatively simple, but building very large ones can entail significant expense, radioactive waste generation, and safety risks. The ISOCS (In Situ Object Counting System) calibration method offers a solution to this problem. It is a convenient tool for calibrating the detector efficiency for a wide variety of source geometries and activity distributions. The ISOCS method consists of a characterization of the detector, user input of source geometry data, and the ISOCS software which uses these to produce the efficiency calibration.

The initial characterization of the germanium detector is performed by Canberra Industries on each individual detector, using the Monte Carlo code MCNP [1]. F. Bronson and L. Wang [2] have documented the satisfactory use of this code for calibrating germanium detector efficiencies. First, an MCNP model of the detector is developed. The model is then independently validated using measurements with a NIST traceable point source. Given the validated model, the detector efficiencies are calculated using MCNP at a large series of point locations in the environment surrounding the detector, over a photon energy range of 50 keV through 7 MeV. The placement of the points in the environment surrounding the detector is done in a quasi-random fashion using the LPT methodology, as originally suggested by V. Atrashkevich and V.V. Kolotov [3]. Using the MCNP calculated efficiencies, response characteristics of the detector are created to cover any point within a sphere 50 meter in radius, centered on the detector, and over an energy range of 50 keV to 7 MeV. The end result is a series of mathematical equations describing the absolute efficiency as a function of energy, angle, and distance from the detector.

The ISOCS calibration software contains a series of mathematical models that can simulate a wide variety of common sample shapes (boxes, cylinders, pipes, spheres, stacked boxes, stacked discs, marinelli beakers etc.). These models allow easy input of appropriate parameters necessary for efficiency computation. The ISOCS software divides each source region into a large number of voxels (1024). A point location is defined within each voxel. The point location within a voxel is determined in a quasi-random fashion. At a given user-specified energy, the detector efficiency is calculated for each voxel. The attenuation due to absorbers within the source and also in the intervening space between the source and the detector is taken into account. If a shield and/or a collimator is defined in the calculation, the software takes into account the additional attenuation due to those. Finally, the efficiencies for all the voxels are summed up at the specified energy. Then a second iteration is done with 2048 voxels. ISOCS then checks whether the desired convergence criterion has been met. If not, the number of voxels is doubled and the calculation continues

at the same energy. Once the convergence criterion is met, the software moves on to the next energy in the user-specified list. If there are multiple source regions, the process is repeated for each source region.

To determine the accuracy of the ISOCS efficiency calibrations, a large number of validation tests (109) were designed and performed.

2. Efficiency Validation Tests

The validation tests were grouped into 3 categories, namely, (1) Field counting geometry, (2) Laboratory counting geometry, and (3) Collimated geometry. Between them, the three categories of tests included 109 different multi-energy sources spanning a large range of sizes and source-detector distances, and both collimated and uncollimated geometries. In each of these tests, a reference efficiency calibration was compared to an ISOCS efficiency calibration at the same geometry. The Monte Carlo code MCNP or the measured data from a multi-energy source was used to generate the reference calibration. The energies of these sources covered the range from low (60-88 keV) to high (1408-1836 keV) energies, with 5-8 energies in between.

The types of validation tests included in the 3 counting geometries are listed in Table 1. The type of tests included in the field counting geometry were those that involved large sources ($> 1 \text{ m}^3$ in volume) and/or large source-detector distances ($> 1 \text{ m}$). A variety of radioactive source distributions were created inside containers that were shaped like boxes, drums and pipes. The containers were filled with materials that one would typically encounter in the field, such as soil, dirt, water etc. About half the number of tests were MCNP simulations, while the other half were radioactive source measurements.

The tests included in the laboratory counting geometry were those that involved small sources, located within a distance of 1 meter from the detector. Except for one MCNP simulation, all the other tests were performed using multi-energy gamma ray standards. The source geometries included vials, bottles, filter papers, and Marinelli beakers.

The tests included in the collimated geometry were those in which the collimator had at least a 20% effect on the ISOCS efficiency. The detector was shielded by a 2.0 inch thick cylindrical side shield. For a given source geometry, ISOCS and reference efficiency calibrations were generated for collimators with opening angles of 180° , 90° , and 30° . The source-detector distance was typically 1 meter. The source dimensions were made large, so that the effect of the side shields and the collimator could be properly tested.

Table 1: Types of Validation Tests in various counting geometries

| Types of Tests in Field Counting Geometry | Types of Tests in Laboratory Counting Geometry | Types of Tests in Collimated Geometry |
|---|---|--|
| 55 gallon Drum of water, 1 m away | 20 ml vial of Mixed Radionuclide Standard | 4 m ³ Dirt Boxes, 2.0 in. thick side shields, 180° Collimator |
| 55 gallon Drum of water, 50% full, a hot spot present | <i>perpendicular to detector axis, at 0, 5, 10, 20, and 25 cm</i> | |
| 60x30x30 cm ³ Box of water, 67% full | <i>facing the detector end-on, at 0, 5, and 10 cm</i> | Line source 20 m in length, 1 meter away |
| 300 liter Box of water | | 2.0 inch thick side shields, 180° Collimator |
| 1 m ³ Box of water, 30 m away | 125 ml bottle of Mixed Radionuclide Standard | 2.0 inch thick side shields, 90° Collimator |
| 1 m ³ Box of water, 1 m away | <i>perpendicular to detector axis, at 0, 5, 10, and 25 cm</i> | 2.0 inch thick side shields, 30° Collimator |
| 1 m ³ Box of air, 1 m away | <i>facing the detector end-on, at 0, 5, 10, and 25 cm</i> | |
| 1 m ³ Box of air, 30 m away | | Plane source 20 m x 20 m, 1 meter away |
| 1 m ³ Box of water, 1 m away, at 90 degrees | Filter Paper in petri dish - Mixed Radionuclide Standard | 2.0 inch thick side shields, 180° Collimator |
| 1 m ³ Box of air, 1 m away, at 90 degrees | <i>facing the detector end-on, at 0, 5, and 25cm</i> | 2.0 inch thick side shields, 90° Collimator |
| 4 m ³ Dirt Boxes of various densities, 1 m away | | 2.0 inch thick side shields, 30° Collimator |
| 4 m ³ Dirt Boxes, point source in the center, 1 m away | NIST Certified ²³⁵ U Standard Reference Material set | |
| 60x30x30 cm ³ Box of water, a hot spot present | <i>Atom % of ²³⁵U abundances: 0.32, 0.72, 1.97, 2.99, 4.52</i> | Line source 4.8 m in length, at a distance of 1 meter |
| 55 gallon Drum of water, facing the detector end-on | | 2.0 inch thick side shields, 180° Collimator |
| Hollow Spherical Shell of water, 1 m away | 1 liter Marinelli Beaker Standards - 1.15g/cc and 1.6 g/cc | 2.0 inch thick side shields, 90° Collimator |
| Pipe full of water, contamination plated on the inside wall | <i>measurements with 20%, 42%, and 60% Ge detectors</i> | 2.0 inch thick side shields, 30° Collimator |
| In Situ Dirt, with detector 1 m away | | |
| Radium, Thorium, and ⁴⁰ K Calibration Pads (Genitron) | 400 ml Marinelli Beaker Standards - 1.15 g/cc and 1.6 g/cc | Measurement of environmental activity from ground |
| Line source, 4.8 m long, 1 m away | <i>measurements with 20%, 42%, and 60% Ge detectors</i> | 2.0 inch thick side shields, 180° Collimator |
| Rotating Calibration Drums, w/line sources inserted | | 2.0 inch thick side shields, 90° Collimator |
| Line source, 80 cm long, at various angles and distances | Point source at various on-axis and off-axis locations | 2.0 inch thick side shields, 30° Collimator |
| Plane source, 3' x 3', at various angles and distances | | |

3. Validation Test Results and Discussion

In each validation test, the ratio of ISOCS efficiency to reference efficiency was determined at each source energy. The data set in each test was divided into three groups in terms of energy; (1) < 150 keV, (2) > 150 keV, (3) data at all energies pooled. For each energy group, a weighted mean of the ratio of ISOCS to reference efficiency was determined. A weighted standard deviation of the ratio was also determined for each energy group. The absolute uncertainties in the reference efficiencies were used to weight the ratio and the standard deviation.

The uncertainties in the ISOCS/Reference efficiency ratio come from the calibration source uncertainties, counting statistics, or the statistical uncertainty in the MCNP results, in addition to the uncertainty due to ISOCS itself. The relative uncertainty due to ISOCS is estimated as follows.

$$[\sigma_{\text{ISOCS eff}} / \text{ISOCS eff}]^2 = [\sigma_{\text{Ratio}} / \text{Ratio}]^2 + [\sigma_{\text{Reference eff}} / \text{Reference eff}]^2$$

It should be noted that the relative uncertainty due to ISOCS for each test indicates the random uncertainty introduced by the ISOCS process. But when taken collectively as an average value over a large number of tests, the ISOCS uncertainty becomes a good estimate of the total uncertainty due to ISOCS, as it also then includes the systematic error in the ISOCS process.

Tables 2, 3, and 4 pool the results of the validation tests for the field, laboratory, and collimated geometries, respectively. The ratios of all the tests belonging to a given geometry, were averaged, and their standard deviation was determined. It is evident that the ISOCS/Reference efficiency ratio comes out reasonably close to unity. The uncertainties (1 σ standard deviation) in the ratios from individual tests were averaged to obtain an *expected* standard deviation. If the standard deviation obtained by pooling together the ISOCS/Reference efficiency ratios from all the tests is close to the *expected* standard deviation, then the data distribution approaches a Gaussian. If not, perhaps there are biases in some of the individual tests which make the distribution deviate from the assumed Gaussian shape.

Table 2: Results for Field Counting geometry

| Result | Data < 150 keV | Data > 150 keV | All data pooled |
|---|----------------|----------------|-----------------|
| Weighted Average of ISOCS/True efficiency ratio | 1.02 | 1.01 | 1.01 |
| Uncertainty in wtd. mean | 0.49% | 0.34% | 0.66% |
| Standard deviation of data | 14.9% | 6.8% | 6.6% |
| Expected standard deviation | 9.9% | 5.2% | 7.5% |
| Avg. ISOCS standard deviation | 8.9% | 4.5% | 6.5% |

Table 3: Results for Laboratory Counting Geometry

| Result | Data < 150 keV | Data > 150 keV | All data pooled |
|---|----------------|----------------|-----------------|
| Weighted Average of ISOCS/True efficiency ratio | 1.05 | 1.02 | 0.97 |
| Uncertainty in wtd. mean | 0.05% | 0.19% | 0.77% |
| Standard deviation of data | 12.8% | 9.9% | 9.6% |
| Expected standard deviation | 8.0% | 5.1% | 6.8% |
| Avg. ISOCS standard deviation | 6.7% | 4.5% | 5.4% |

It is difficult to pin-point the sources of biases that make the data deviate from a Gaussian behavior. The source of bias could be from ISOCS, the detector characterization process, systematic errors in measurements, systematic errors in the standard source calibration, or systematic errors in MCNP simulation. Every effort has been made to alleviate or eliminate the known biases in the data. For example, in the laboratory geometry, when sources containing nuclides such as ^{60}Co , ^{88}Y , and ^{152}Eu were counted close to the detector (< 10 cm), the data was corrected for cascade summing losses in the full energy peaks.

For tests involving thick lead shields and collimators with small opening angles, the ISOCS efficiency is greater than the reference efficiencies, especially at lower energies. This could be because of the algorithm used in ISOCS to estimate the collimator attenuation. A new collimator algorithm has been devised and tested. This new algorithm has improved the efficiencies significantly, and will be incorporated into a future version of ISOCS.

Table 4: Results for Collimated Geometry

| Result | Data < 150 keV | Data > 150 keV | All data pooled |
|---|----------------|----------------|-----------------|
| Weighted Average of ISOCS/True efficiency ratio | 1.10 | 1.09 | 1.09 |
| Uncertainty in wtd. mean | 0.80% | 0.89% | 1.27% |
| Standard deviation of data | 27.7% | 24.6% | 23.9% |
| Expected standard deviation | 8.0% | 9.9% | 12.5% |
| Avg. ISOCS standard deviation | 7.7% | 7.6% | 10.5% |

Another source of bias in heavily shielded or collimated geometries, is coherent scattering of photons. Earlier tests using the total photon cross sections gave low ISOCS efficiencies in these cases. The current release of ISOCS now uses cross sections which do not include coherent scattering cross sections. Now, the ISOCS efficiencies are somewhat higher than the true value, but closer to the true efficiency.

4. Conclusions and Future work

The validation tests reveal that the ISOCS efficiency calibration is fairly accurate for most applications. In the case of field and laboratory counting geometries, the average ISOCS to reference efficiency ratios was 1.01 ± 0.007 and 0.97 ± 0.007 , respectively. For the collimated geometry, the ISOCS to reference efficiency ratio was 1.09 ± 0.014 . This is still acceptable for typical ISOCS applications where there are usually other sources of error that are more significant. A new collimator algorithm has been devised and tested, and it has significantly improved the ISOCS efficiencies for collimated geometries. Also, a new detector characterization process has been developed, and is in its final phases of testing. This reduces the ISOCS error component significantly, which should greatly reduce the uncertainties in the laboratory geometries.

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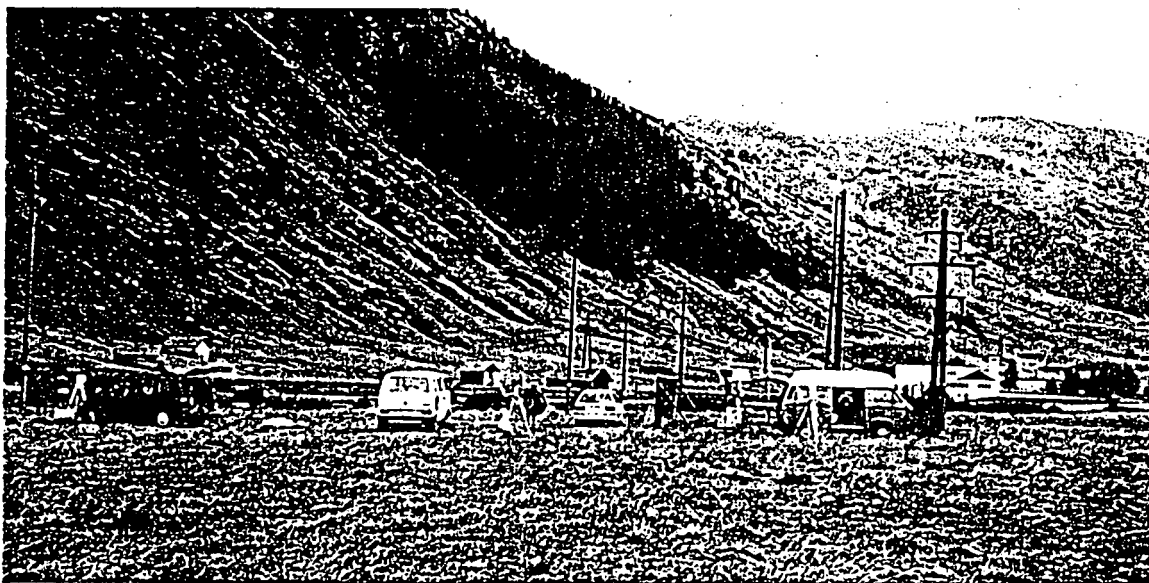
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10th Regular Workshop on
Mobile Radiological Laboratories
Organised by Swiss Federal Office of Public Health
Swiss Federal Nuclear Safety Inspectorate and NC Laboratory

Gordola, Switzerland, October 6 – October 10, 1997

GORDOLA

SWITZERLAND 97



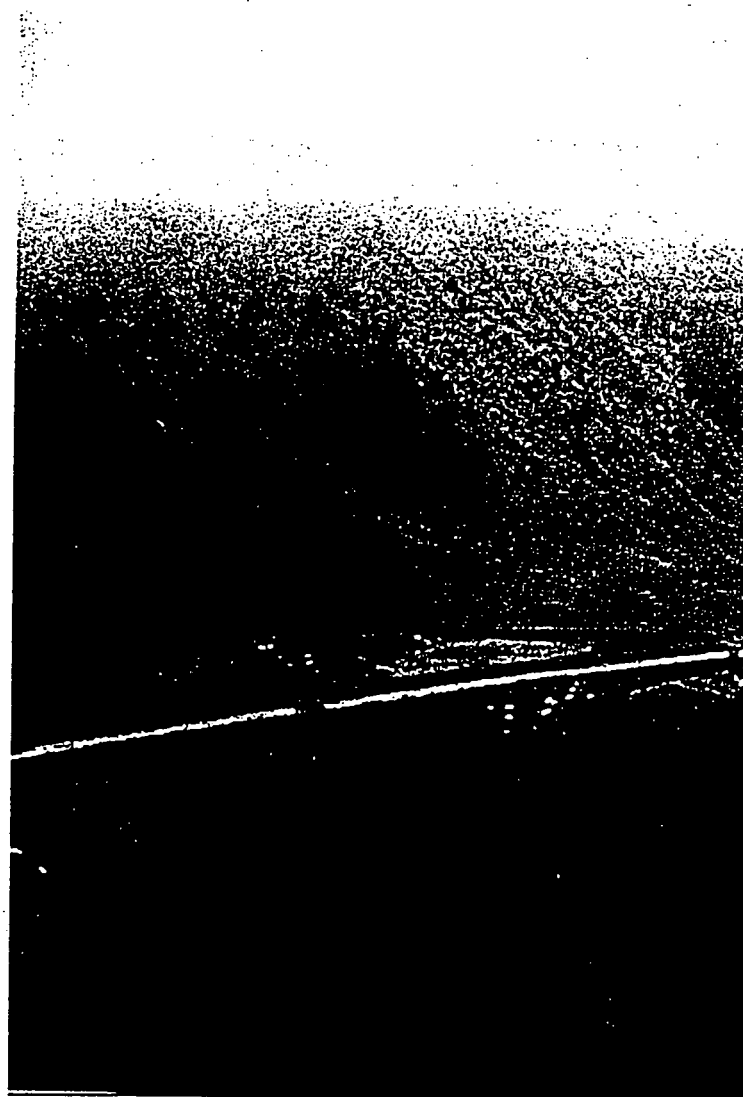
INTERCOMPARISON MEASUREMENTS

Ch. Murith, A. Gurtner, S. Segat, W. Baur, M. Schibli, F. Byrde, M. Astner

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GORDOLA 97
INTERCOMPARISON MEASUREMENTS



Ch. Murith, A. Gurtner, S. Segat, W. Baur, M. Schibli, F. Byrde, M. Astner

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Preface

After the reactor accident in Chernobyl, the necessity of having quick and reliable methods for the determination of environmental radionuclide contamination became evident. For this reason, an increase of interest in the in situ gamma spectrometry arose for many mobile radiological laboratories. Periodical intercomparison exercises have been organised since then by different institutions in European countries in order to improve the measuring methods and to gain a good basis for quality assurance.

At the 9th workshop in Bled (Slovenia), the decision was made that the 1997 intercomparison measurements will be organised by the Swiss Federal Office of Public Health, in Switzerland. The 10th Workshop was held at Gordola, Switzerland from October 6 to October 10, 1997. Twenty teams from ten countries registered for the workshop from which 17 arrived and participated in the exercises. There were altogether 45 participants and two observers. List of participants is in Appendix 3.

The aims of 1997 intercomparison measurements were:

- ✓ To check the state-of-the-art of in situ gamma ray spectrometry for its standard application and also to examine new or future development.
- ✓ To improve cooperation among different institutions in Europe.
- ✓ To test the capacity of the teams to produce results at the spot.

The workshop organisation and concluding report received the agreement of the three involved Swiss administration Departments.



Bernard Michaud

Head of Main Unit Radiation
Protection and Chemical
Products



Serge Prêtre

Director of Swiss Federal
Nuclear Safety Inspectorate



Bernhard Brunner

Director of NC Laboratory

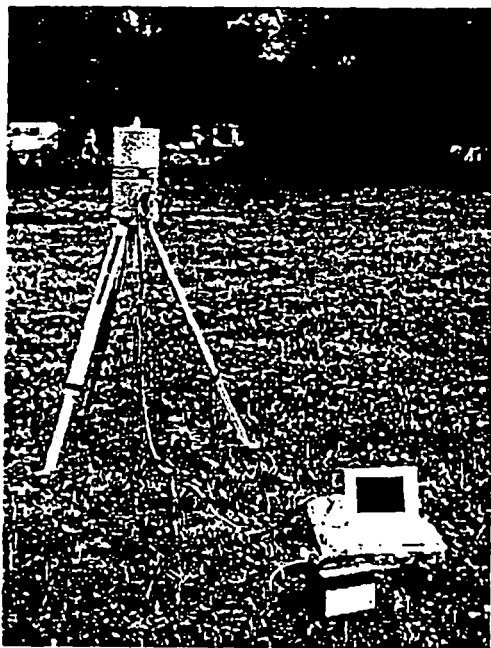
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1. Introduction

Gamma-ray spectrometry with portable detectors has become a common method to determine activity levels in the ground and radionuclide specific dose quantities mostly at a height of 1m above ground. The main advantages of the method, compared to measurements of soil samples in the laboratory, are that results can be obtained at the measurement site within a relative short time interval –one hour or less- and that the measurement averages over small scale spatial source variations, which are not relevant for gamma dose rates in air. This is an important advantage over soil sampling where many samples would be required to insure a statistically valid result.



Due to the pioneering work of Lowder et al. (1964) and of Beck et al. (1964; 1972), a widely accepted procedure has

been developed for the determination of nuclide-specific soil activities and resulting ambient dose rates.

The International Commission on Radiation Units and Measurements published 1994 a reviewed report about gamma-ray spectrometry in the Environment (ICRU – Report 53), which can be adopted as a fundamental updated guide in this field.

New approaches using Monte Carlo modelling or more advanced methods involving spectral unfolding procedures were investigated by some teams. Depending on the teams coaxial germanium p-type and n-type detectors were used with relative efficiencies between 10 and 56%. Most of the teams used common commercial software's plus own procedures. For the calibration procedures and the calculation parameters some discrepancies are still observed. Especially influences of dead layer and entrance window thickness, angular corrections, emission probabilities and conversion factors (count rates in specific activities and specific activities in dose rates) are concerned. An effort in harmonising these parameters would reduce systematic uncertainties and improve the agreement between the results of the different teams, which are reported in section 3.

2. Program of the workshop

The program of the workshop consisted of field exercises and conferences.

FIELD EXERCISES: (see also section 3)

The following field exercises were prepared:

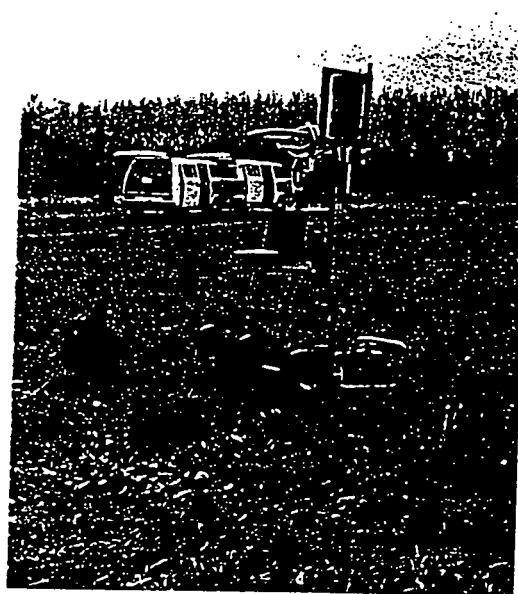
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|-----------------------|--|
| <u>Exercise No 1:</u> | In situ gamma spectrometry of natural and artificial radionuclides and their contribution to ambient dose rate at Gordola in the open country near the river Ticino. |
| <u>Exercise No 2:</u> | In situ gamma spectrometry of a buried source (identification, depth and activity). |
| <u>Exercise No 3:</u> | In situ gamma spectrometry of natural and artificial radionuclides and their contribution to ambient dose rate at Hinterrhein in an alpine site. |
| <u>Exercise No 4:</u> | Search for lost sources with dose rate measurements. |

CONFERENCES: (see also section 5)

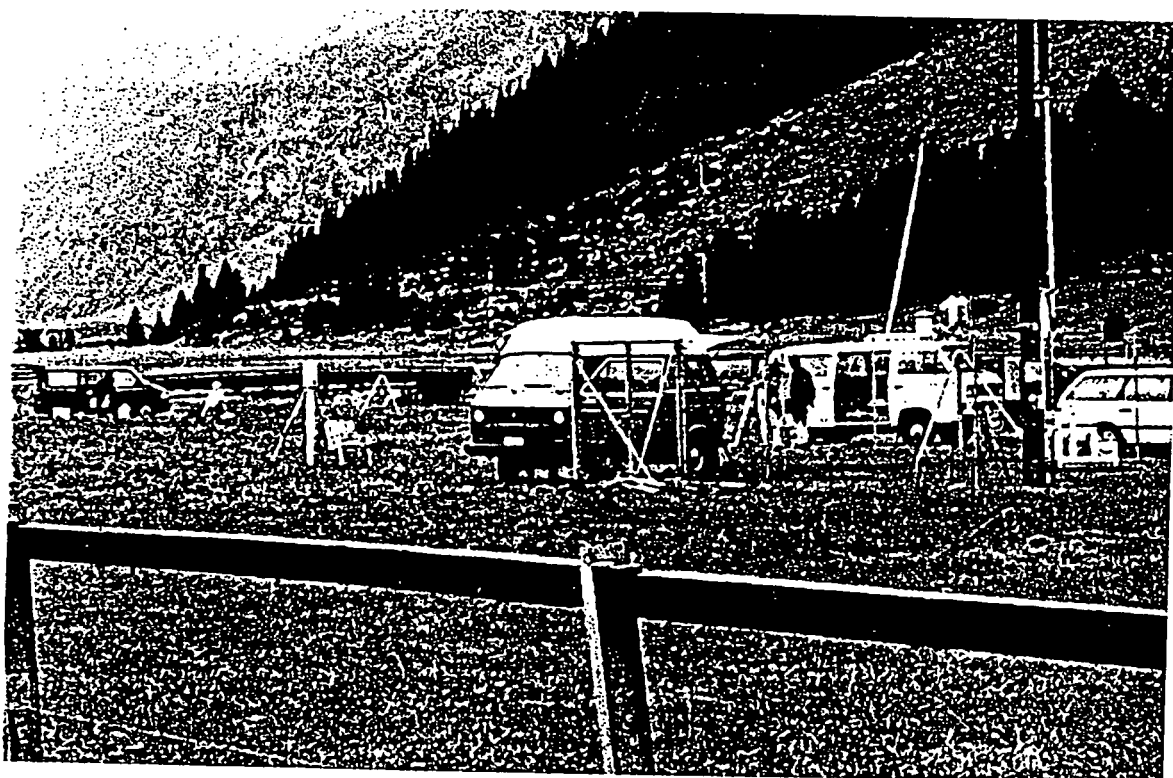
- *About the influence of topography on the accuracy of activity measurements.*
- *Geostatistical assessment of radionuclide content in Swiss soils.*
- *Track down Radon with Gaston.*
- *Methods used by IAEA Laboratories Seibersdorf for gamma-ray measurements in remote locations.*
- *DART: Portable multichannel analyser for in situ spectrometry.*
- *ISOCs: A novel technique for in situ gamma spectroscopy.*
- *INTERWINNER: The solution for your in situ spectroscopy.*
- *Recent developments on field instrumentation's for in situ spectrometry.*
- *Preliminary results and final discussion.*

3. Results

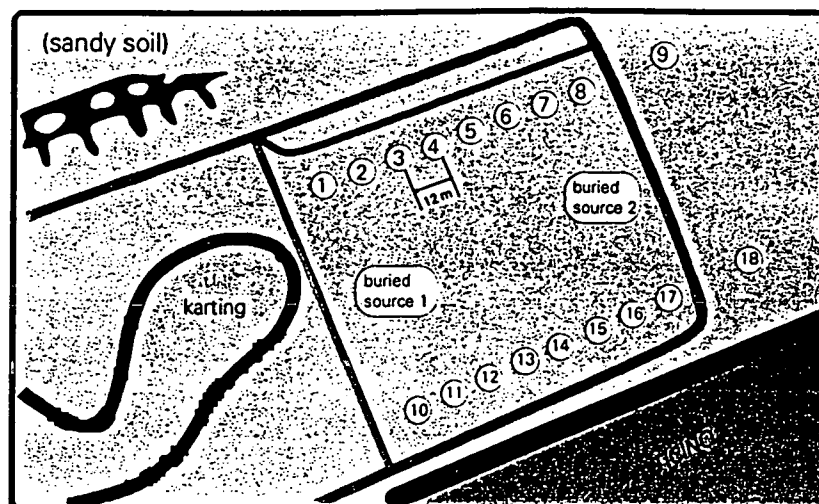
Measurements sites at Gordola



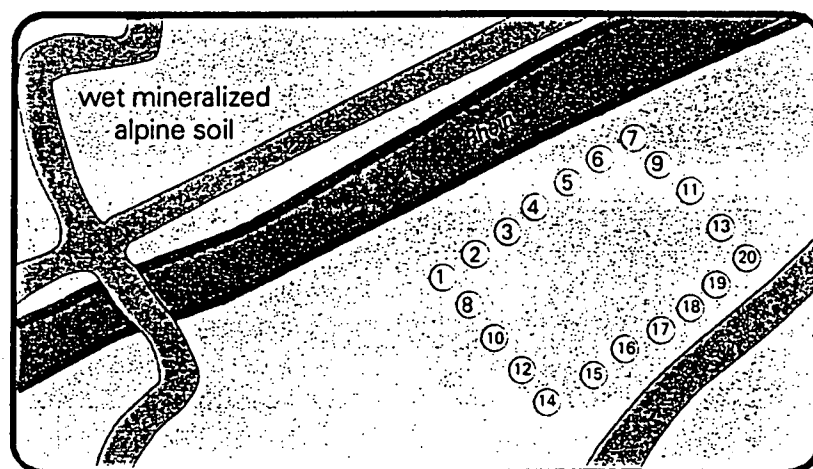
Measurements sites at Hinterrhein



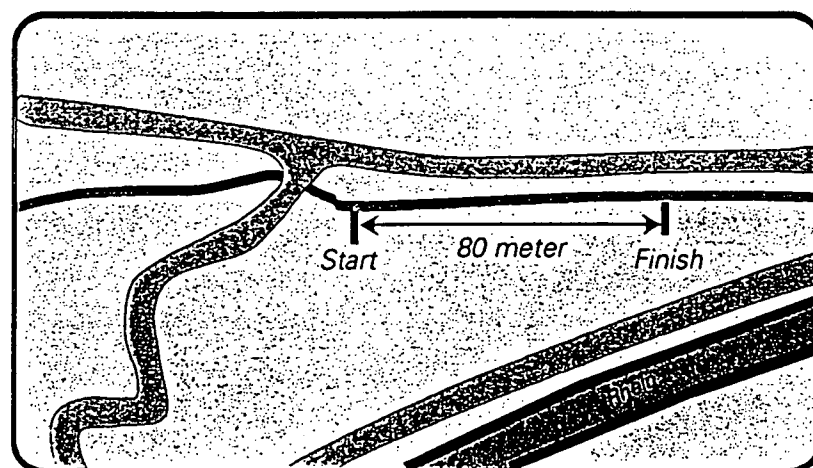
Site : GORDOLA (TI) / Exercise 1 & 2



Site : HINTERRHEIN (GR) / Exercise 3

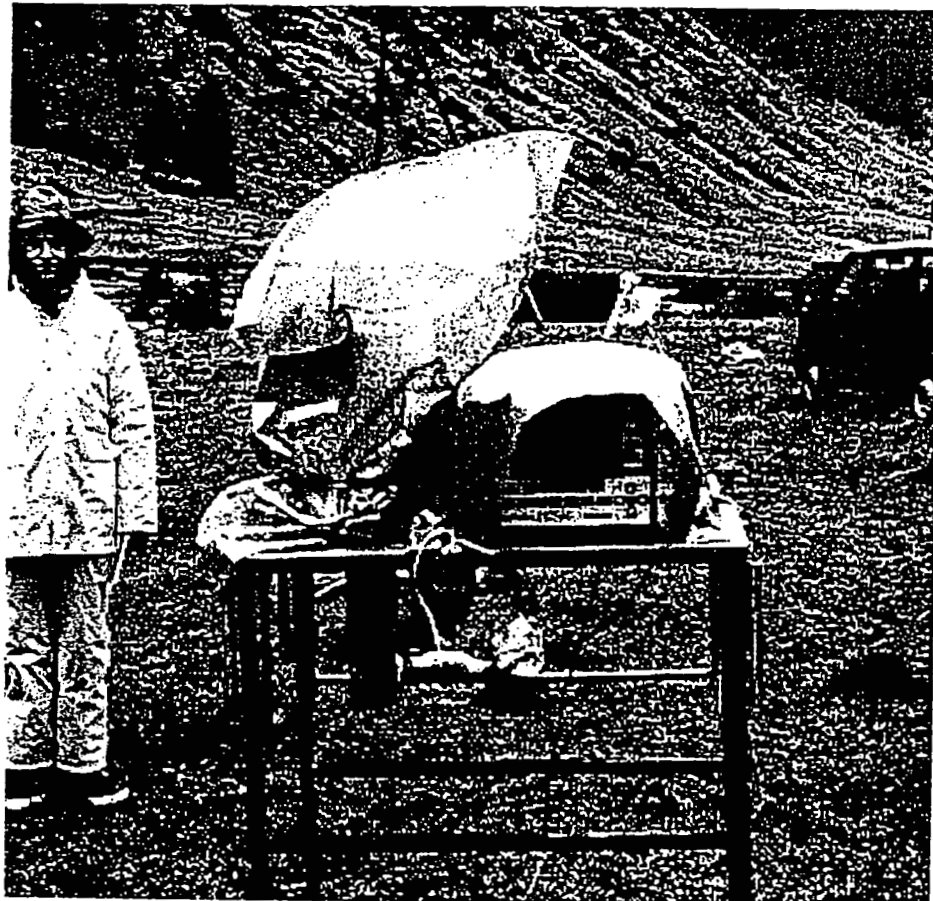


Site : HINTERRHEIN (GR) / Exercise 4



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EXERCISES



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EXERCISE No 1

In situ gamma spectrometry at Gordola (TI), altitude 200m

Aim: To measure concentrations of natural radionuclides assuming uniform distribution in soil and to determine ^{137}Cs specific activities for uniform distribution ($\beta \rightarrow \infty$) respectively for ideal plane distribution ($\beta = 0 \text{ g.cm}^{-2}$, recent deposition without penetration into the soil). To compare measured dose rate with calculated ones from in situ spectra.

Although the assumption of a uniform profile in the soil for natural emitters is generally safe in most natural situations, cases where there is markedly different soil strata of varying nuclide concentration may produce anomalous results. Thus soil profiles were analysed in laboratory and confirmed that a uniform assumption was realistic for the sandy soil at Gordola. For the evaluation of the ^{238}U series, the participating teams mostly based their results on radon daughters ^{214}Pb and ^{214}Bi . This important gamma emitting progeny may not be in equilibrium with ^{226}Ra because ^{222}Rn escapes from the soil. At Gordola, where measurements were not performed during precipitations, reported data didn't take into account the loss due to radon escape, which can be offsetted by the contribution to the fluence rate at the detector from the progeny in the air. Only a few teams tried to estimate ^{226}Ra using 186 keV peak, which is affected by ^{235}U contribution. An accurate determination would need a sensitive identification at lower energies that generally remains problematic for in situ spectrometry.

For ^{137}Cs contents in the soil at Gordola, the chosen area was very interesting. Due to repeated floods, the ^{137}Cs distribution is markedly different near Ticino river compared to more distant sites from the river. This particularity is confirmed by the measurements (figures 4 and 5). For an actual ^{137}Cs inventory of about 30 kBq/m^2 (80% from Chernobyl and 20% from bomb fallout), soil profiles analyses showed that near the river cesium is mostly concentrated in deeper layers (15-25 cm because of alluvial deposits), while at the other end of the measurement field most of the activity remains still in the upper layer (0-10 cm, less or no alluvial deposits). Following the ^{137}Cs behaviour with in situ spectrometry since 1986 and describing its transfer in deeper layer by an evolution of β in the exponential model [Ref.8], an abnormal increase of β was especially observed in 1994 after memorable floods from October 1993 (important alluvial deposit).

Comparisons performed by some teams between measured dose rates and calculated ones from in situ spectra showed good agreements (within $\pm 10\%$) taking into account the cosmic contribution of about 35 nGy/h .

Remarks: In each figure the average and the standard deviation of measured values are also represented without the mentioned values not taken into account. In figures 4 and 5, the measurements performed by the teams 5 and 17 for the sites more distant from the river correspond both to the site 1, where the measured lower ^{137}Cs concentrations could be explained by the proximity of the karting track. Considering the 18 sites of the area, the extreme heterogeneous distribution of ^{137}Cs induces discrepancies up to a factor ten for the measured ^{137}Cs concentrations by ignoring its real depth profile (see appendix 3).

Figure 1: ^{40}K concentrations in soil at Gordola (TI)

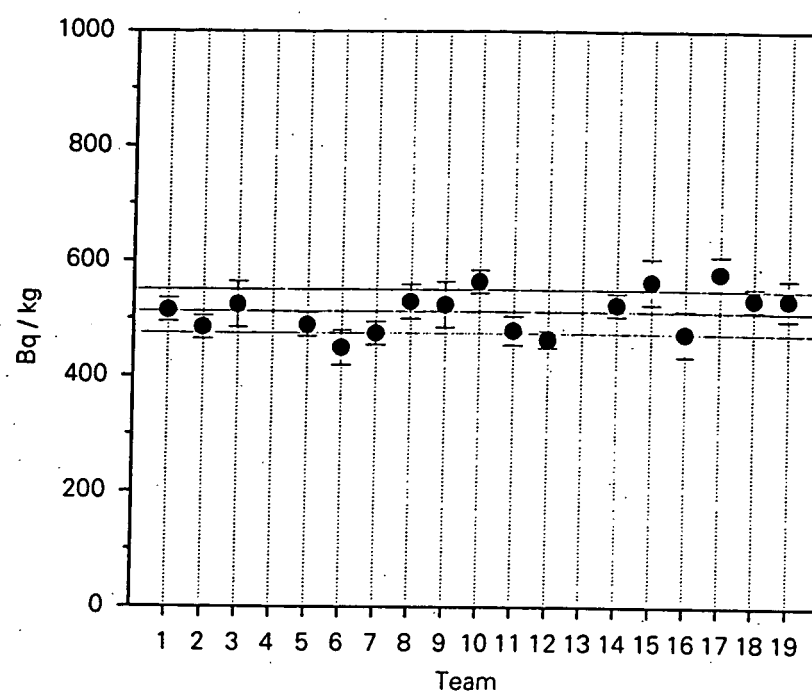
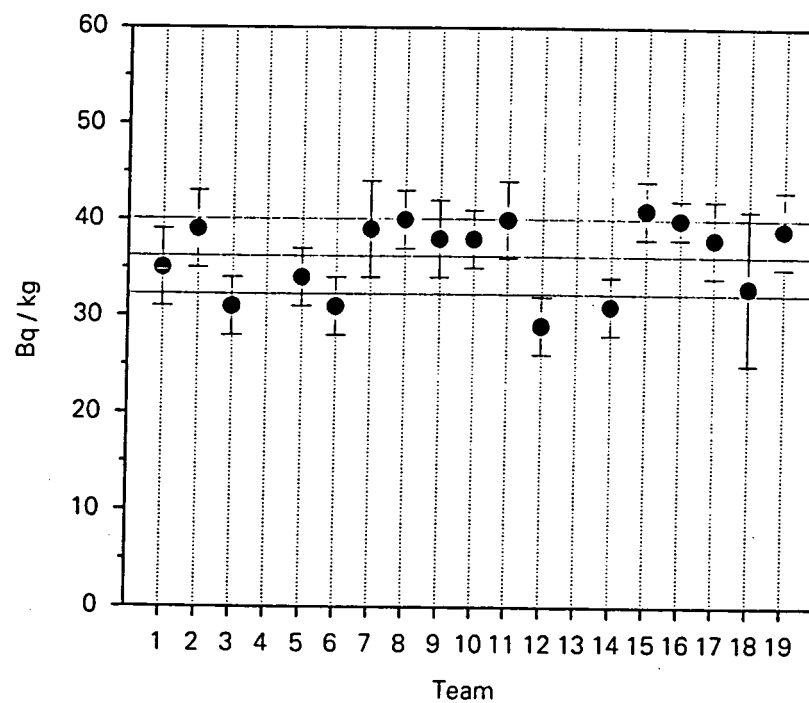


Figure 2: ^{228}Ac (from ^{232}Th series) concentrations in soil at Gordola (TI)



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Figure 3: Radon daughters concentrations (^{238}U series) in soil at Gordola (TI)

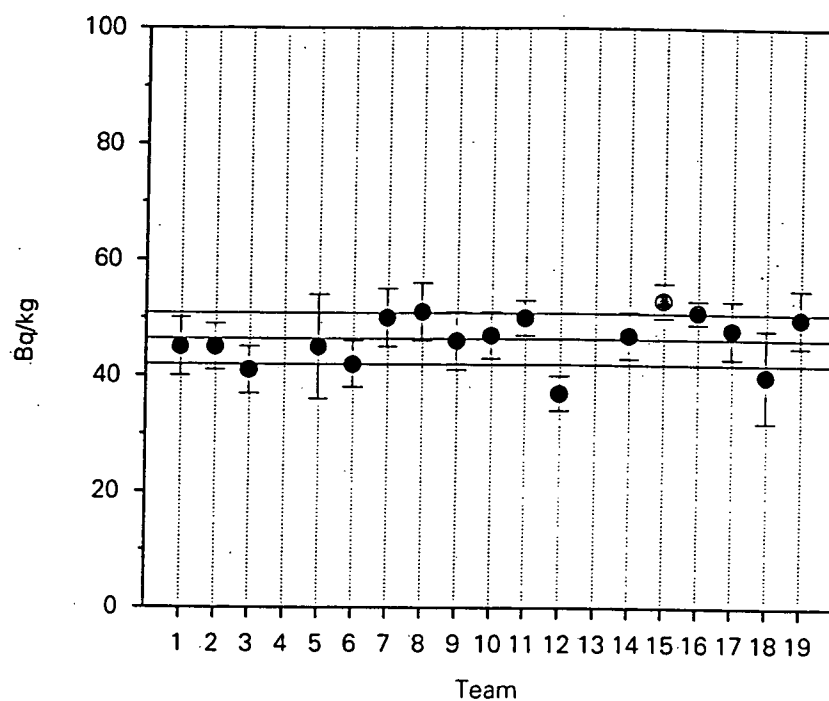


Figure 4: ^{137}Cs concentrations in soil assuming uniform distribution at Gordola (TI)

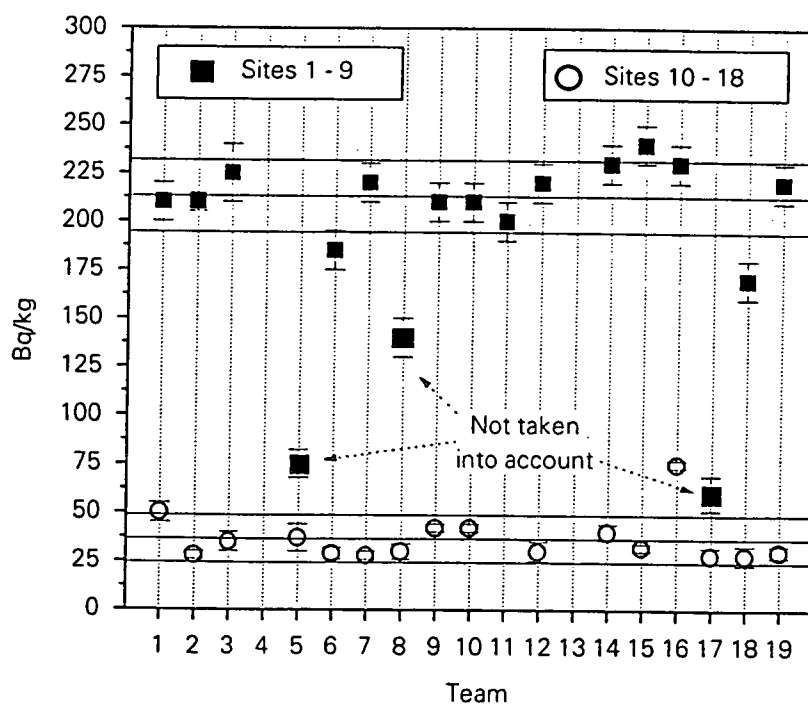


Figure 5: ¹³⁷Cs concentrations assuming an ideal plane distribution at Gordola (TI)

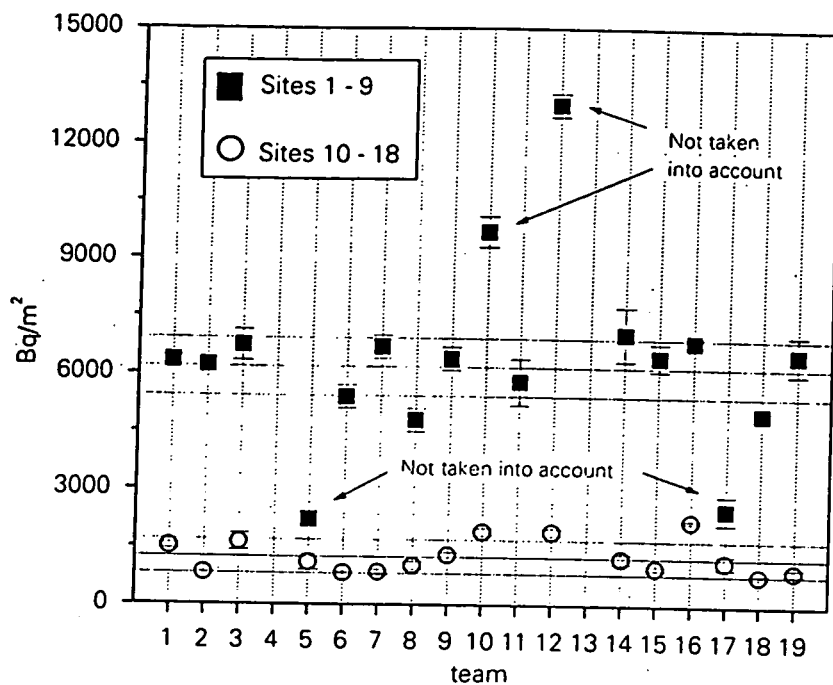
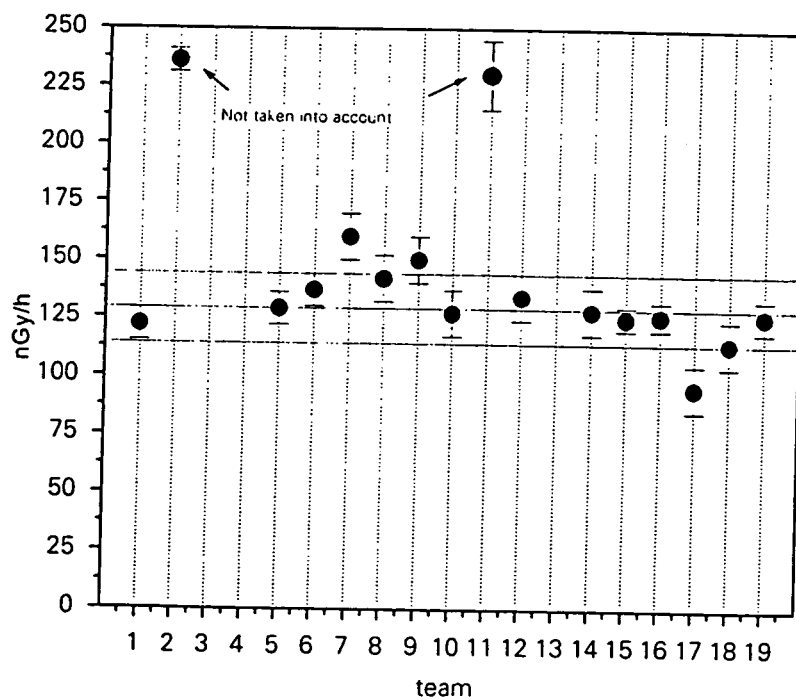


Figure 6: Measured ambient doses rates 1m above ground at Gordola (TI)



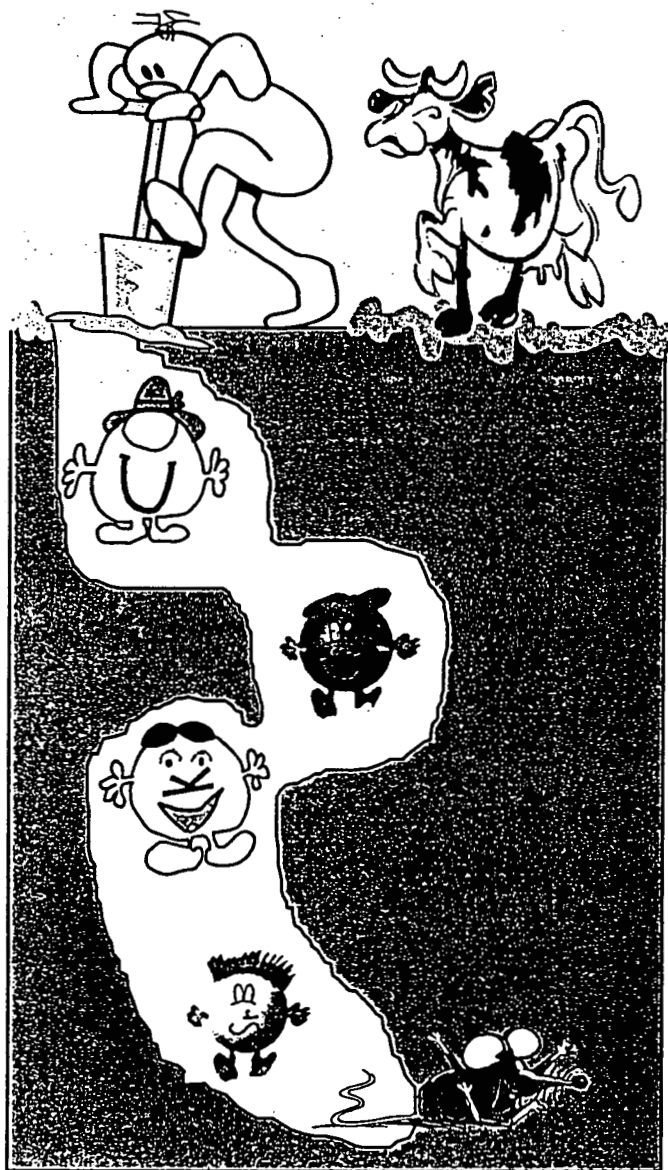
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EXERCISE No 2

In situ gamma spectrometry of buried sources (figures 7 and 8).

Aim: To identify a buried source, to determine its depth in the soil and its activity

Two ^{226}Ra sources with respectively 32.3 MBq and 51 MBq activity were buried 51 cm deep in the soil. The density of the soil above both sources $\rho = 1.4 \text{ g/cm}^3$ was given. Most of the teams calculated the depth of the source in the soil by measuring the attenuation of one energy peak at two different distances (ground - detector) respectively the attenuation of two different energies (e.g. 609, 1764 keV) at a defined height above ground. The activity was then obtained from the absolute calibration of the detector. Some teams took also into account the environmental radon daughters progeny, which could affect the accuracy of the results by 5 to 10 %. All the teams identified ^{226}Ra and estimated depths between 30 cm and 100 cm. Not taking into account 2 extreme results, the mean depth (15 teams) corresponds with $51 \pm 6 \text{ cm}$ to the certificated value 51 cm.



By the calculation of the activity only 7 teams obtained a rather good estimation compared to the certificated value. A similar observation was made by the last intercomparison in Slovenia with a buried ^{65}Zn source.

Although this exercise is an unusual application of in situ spectrometry, further investigations are needed to improve the reliability of the results.

Figure 7: Estimated depth of buried ^{226}Ra sources

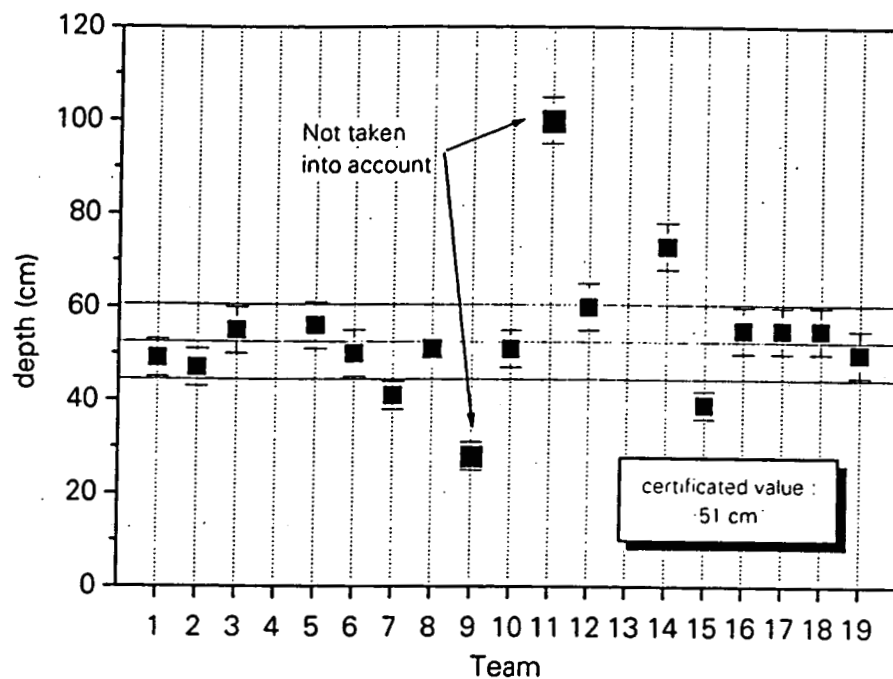
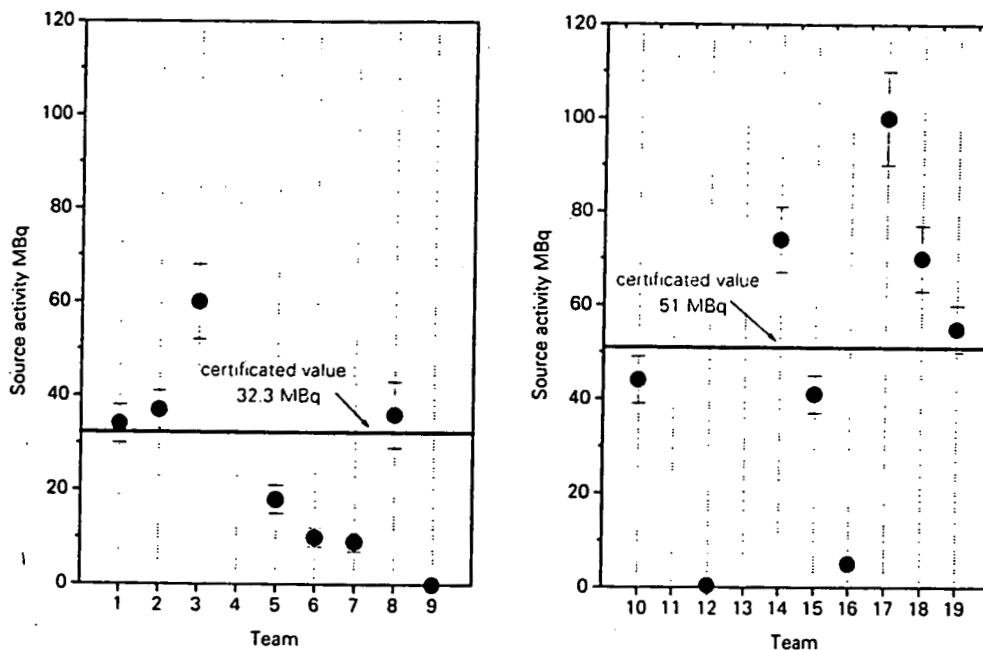


Figure 8: Estimated activity of buried ^{226}Ra sources



EXERCISE No 3

In situ gamma spectrometry at Hinterrhein (GR), altitude 1600m (figures 9 to 14)

Aim: To measure concentrations of natural radionuclides assuming uniform distribution in soil and to determine ^{137}Cs specific activities for uniform distribution ($\beta \rightarrow \infty$) respectively for an exponential distribution ($\beta = 1 \text{ g.cm}^{-2}$, recent deposition with penetration into the soil). To measure ambient dose rates and to calculate individual nuclide contributions from in situ spectra

Measurements at Hinterrhein were performed under hard climatic conditions (heavy rainfalls and strong winds). Some teams encountered difficulties but didn't lose heart. Measurements of ^{214}Pb and ^{214}Bi are problematic during and up to a few hours after precipitation events since they are scavenged from the atmosphere and deposited on the ground. It results an overestimation for ^{238}U determination based on radon progeny. As shown in figure 10, the variability of radon daughter's concentrations was thus more significant at Hinterrhein than at Gordola. Since the soil at the wet alpine site Hinterrhein consists of clay in the upper layer (0 – 5 cm) and became deeper very stony, ^{137}Cs is still mostly concentrated in the upper layer as confirmed by profiles analyses (see appendix 3). Periodical in situ measurements performed since 1986 at Hinterrhein assuming an exponential distribution model confirm a weak evolution of β (up to 2 g.cm^{-2} 10 years after Chernobyl deposition resp. up to 6 g.cm^{-2} for the bomb cesium). The global inventory represented about 17 kBq/m^2 at reference date 1 May 1986 (14 kBq/m^2 from Chernobyl and 3 kBq/m^2 remaining from bomb fallout).

Comparisons performed by some teams between measured doses rates and calculated ones from in situ spectra showed also at Hinterrhein good agreement (within $\pm 10\%$) taking into account the cosmic contribution of about 60 nGy/h .

Remarks: In each figure the average and standard deviation of measured values are also represented. Compared to Gordola, the ^{137}Cs distribution appears less heterogeneous at Hinterrhein, where the discrepancies for the measured ^{137}Cs concentrations are within a factor 2. A few teams also detected ^{134}Cs with concentrations between 2 and 4 Bq/kg corresponding to 100 respectively 200 Bq/m² for $\beta = 1 \text{ g.cm}^{-2}$.

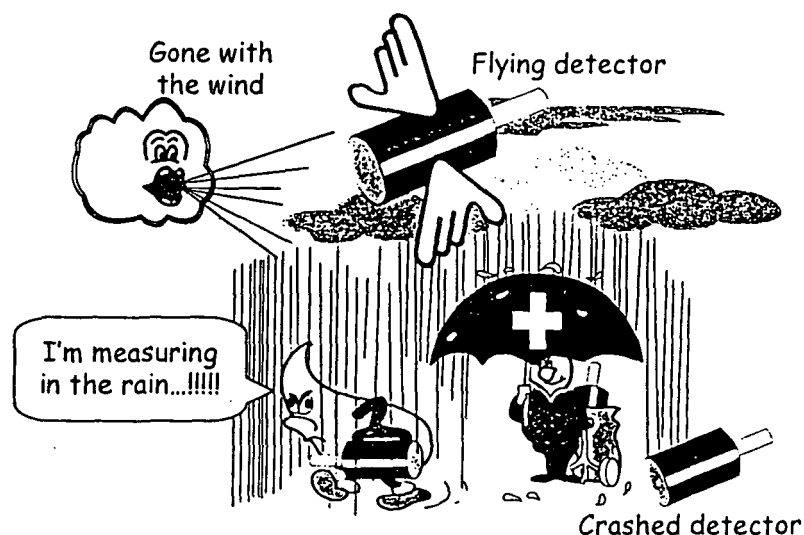


Figure 9: ^{40}K concentrations in soil at Hinterrhein (GR)

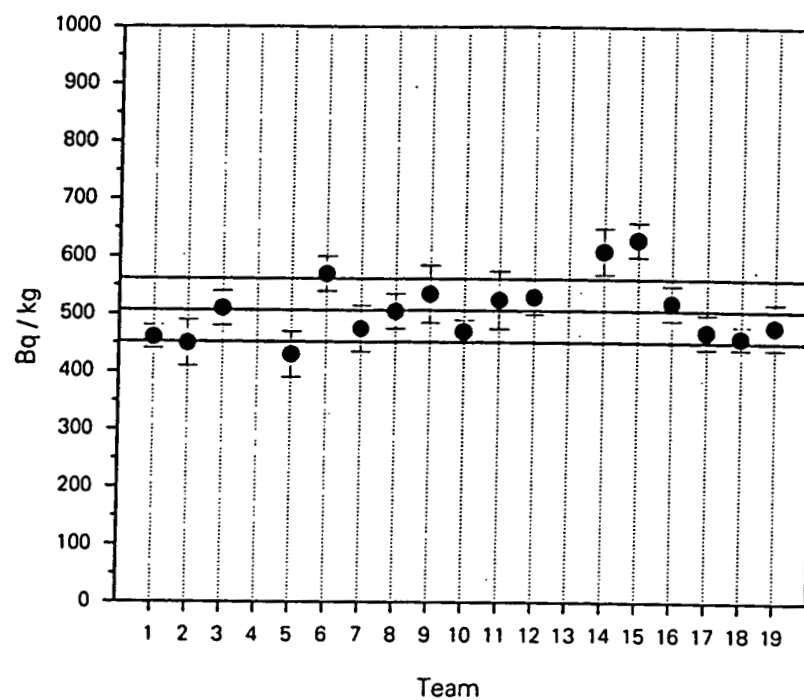
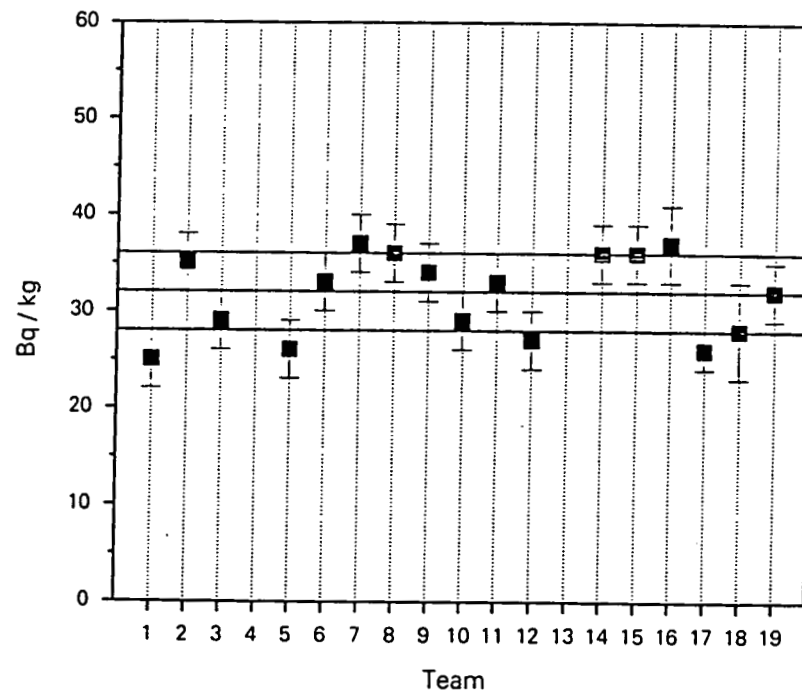


Figure 10: ^{228}Ac (from ^{232}Th series) concentrations in soil at Hinterrhein (GR)



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Figure 11: Radon daughters concentrations (^{238}U series) in soil at Hinterrhein (GR)

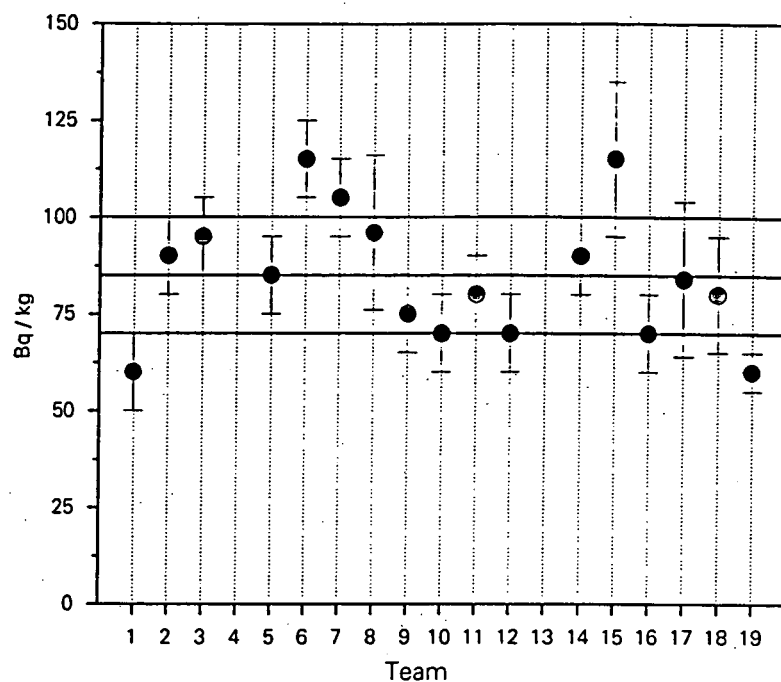


Figure 12: ^{137}Cs concentrations in soil assuming uniform distribution at Hinterrhein (GR)

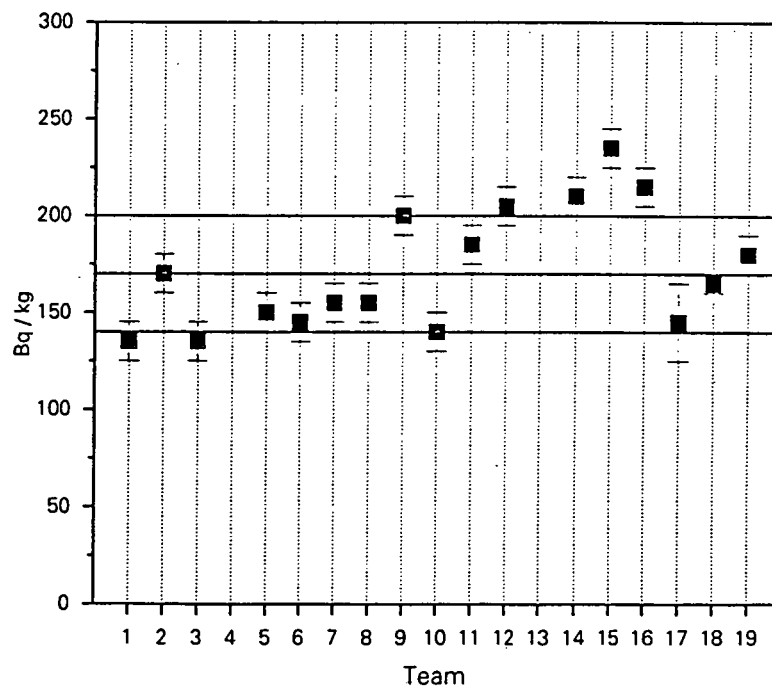


Figure 13: ^{137}Cs concentrations assuming exponential distribution ($\beta = 1$) at Hinterrhein (GR)

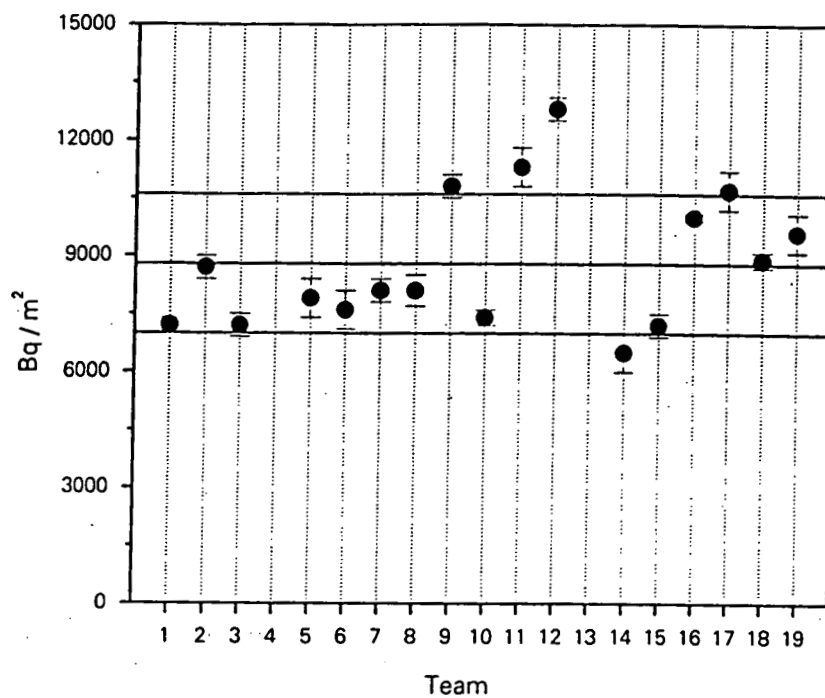
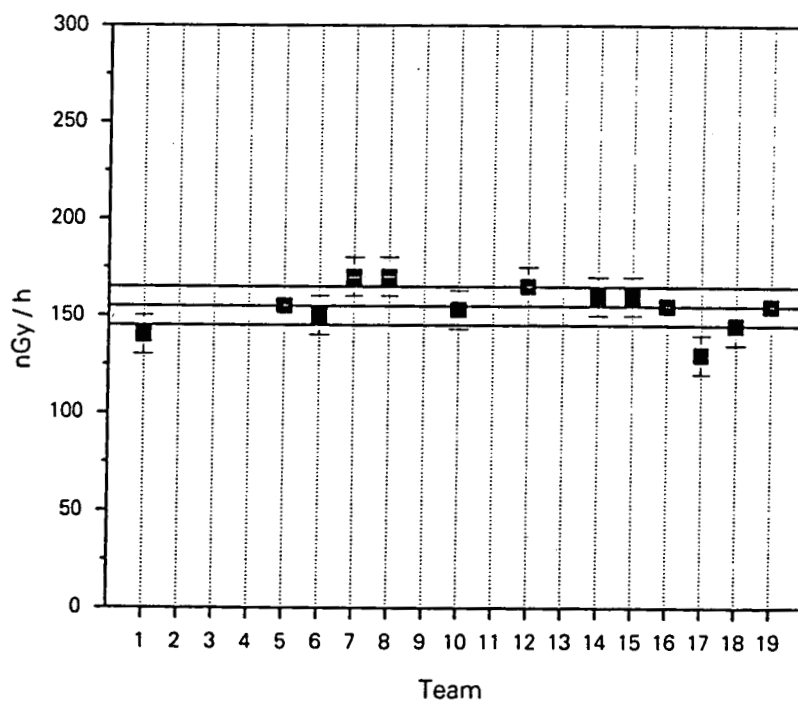


Figure 14: Measured ambient dose rates 1m above ground at Hinterrhein (GR)



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EXERCISE No 4

Search for „lost“ sources (figure 15)

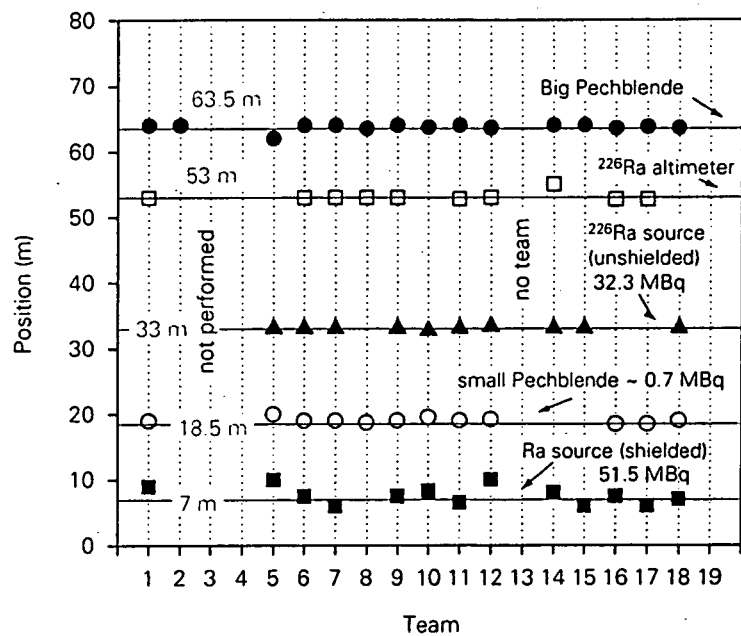
Aim: To find „lost“ sources with dose rate measurements walking on a predetermined way

The teams had to walk on a marked way and to localise dose rate maxima corresponding to hide sources.

The team which participated to this exercise generally found successfully the hide sources.



Figure 15: Search for "lost" sources



4. Conclusions

Gamma-ray spectrometry in the environment has been established as a rapid and sound method for the determination of radionuclide activities and dose-rate quantities. A synthesis of the results of the 10th intercomparison exercise is given in table 1. The largest source of uncertainty in the determination of radionuclide activities from in situ gamma ray spectrometry remains the assumption that has to be made on the depth distribution of the radionuclides in soil. The problems are closely related to the age of the fallout and to the characteristics and history of the site. Nevertheless a lack of knowledge about the distribution does not significantly influence the results of the nuclide specific ambient dose rate, which is derived from the measured gamma spectrum.

The workshop showed that an additional effort for an international standardisation of numerical parameters (e.g. emission probability) and in the calibration procedure would contribute to improve the reliability of the results. Such exercises also are needed to strengthen the preparedness of the emergency teams.

The workshop proved that results can be produced at the spot, which is of primary importance for such mobile laboratories. It unforeseen confirmed the ability of the teams to measure under bad climatic conditions, even if some amelioration's are achievable to master encountered problems. Last but not least an important aim of such intercomparison consists of promoting the cooperation among different emergency teams. Regrets remain that new teams, especially from neighbour countries as France or Italy couldn't take part at the 10th workshop.

The next participating opportunity will be the 11th workshop to be held in Slovak Republic 1998 (see page 39). The organiser is the team of the Institute of Preventive and Clinical Medicine. Agreement was also reached about the opportunity to hold the 12th workshop 1999 in the exclusive zone of Chernobyl NPP. It will be jointly organised with the Ukrainians colleagues involving possibly IAEA.

Table 1: Synthesis of the in situ results at Gordola (200m) and Hinterrhein (1600m)

| Bq/kg (mean of all teams) | ⁴⁰ K | ²³⁸ U series | ²³² Th series | ¹³⁷ Cs |
|------------------------------|-----------------|----------------------------|-----------------------------|--|
| Gordola | 515 ± 40 | 46 ± 4 | 36 ± 4 | 210 ± 20 (sites: 2-9) 70 ± 7 (sites: 1,10) 34 ± 7 (sites: 11-18) |
| Hinterrhein | 510 ± 50 | 85 ± 15 | 32 ± 4 | 170 ± 30 (sites 1-20) |

| nGy/h calculated | ⁴⁰ K | ²³⁸ U series | ²³² Th series | Terrestrial | Cosmic | Natural (total) | nGy/h measured |
|---------------------|-----------------|----------------------------|-----------------------------|-------------|--------|--------------------|--------------------|
| Gordola | 21 ± 2 | 21 ± 2 | 22 ± 2 | 64 | 35 | 99 | 115 ± 9 130 ± 9 |
| Hinterrhein 2) | 21 ± 2 | 39 ± 7 | 19 ± 2 | 79 | 59 | 138 | 155 ± 10 |

1) based on ICRU Report 53 factors.

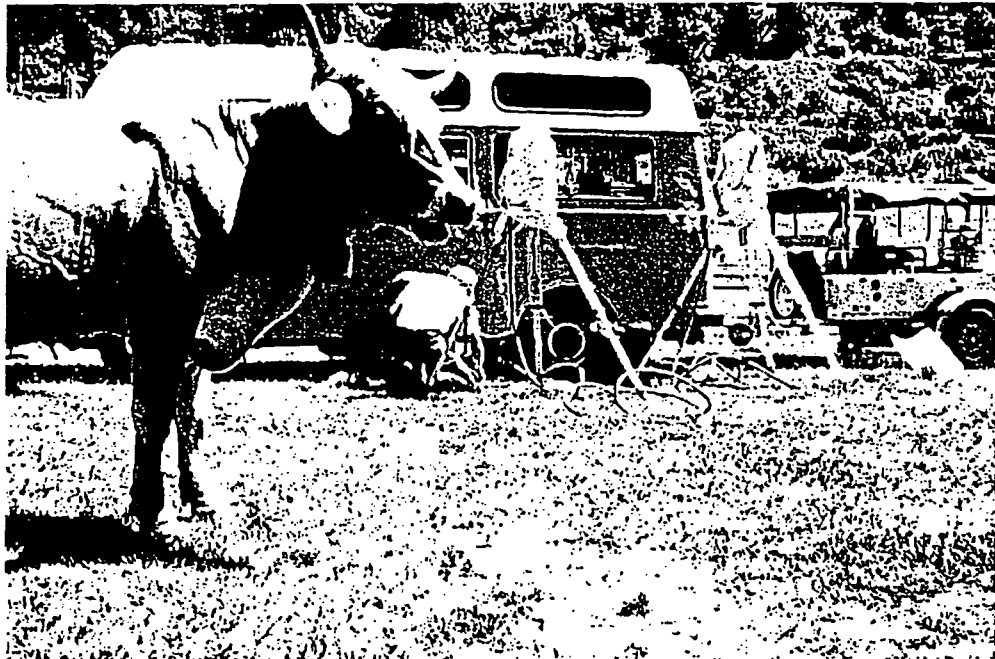
2) Measurements performed during precipitations show partially higher ²³⁸U series contributions (up to a factor 2)

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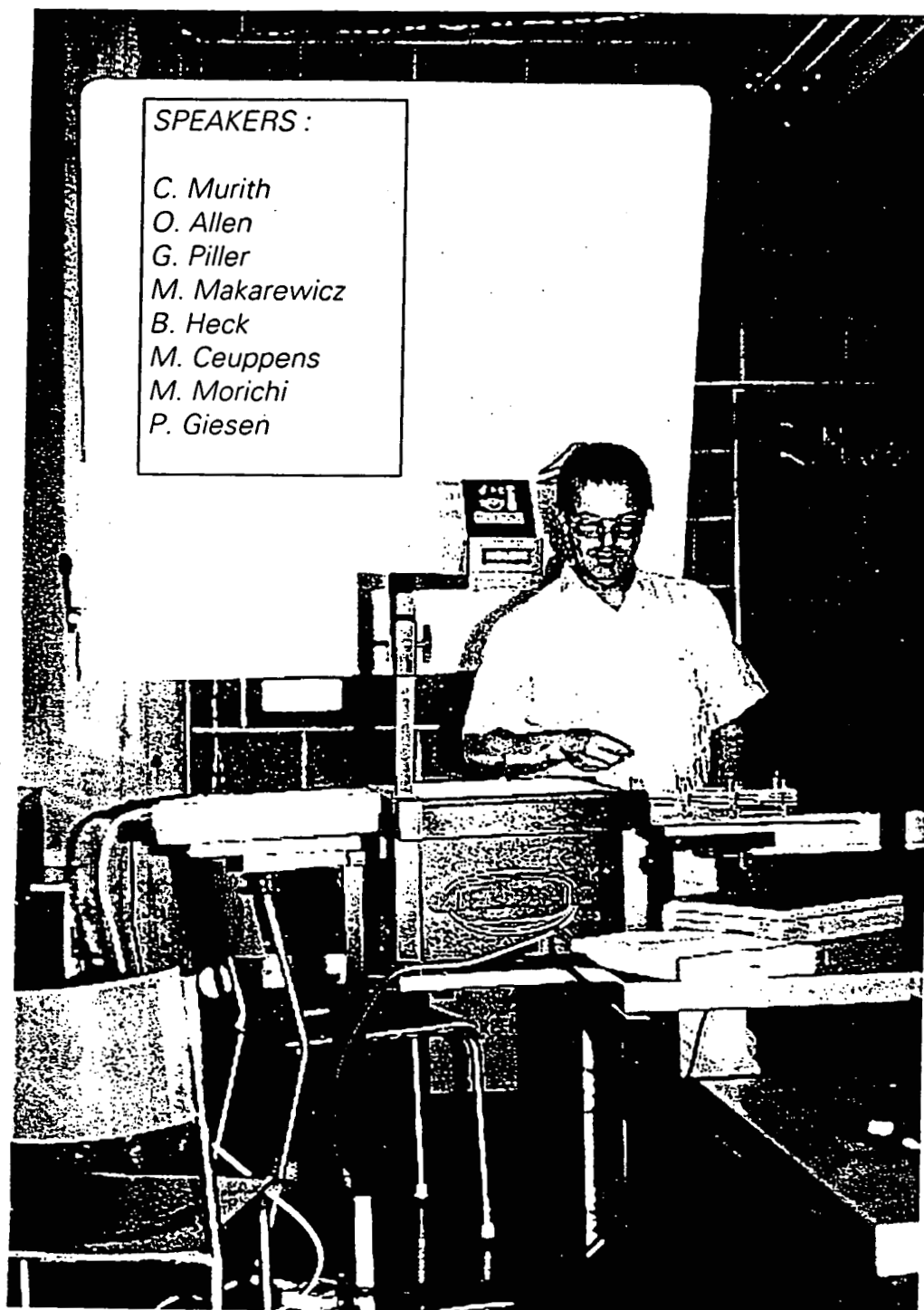
The ^{137}Cs dose rate contribution can be estimated from the difference (measured – calculated) \Rightarrow 16-31 nGy/h at Gordola and 17 nGy/h at Hinterrhein. This estimation agrees with the contribution calculated by the teams from the corresponding in situ spectra.

The real ^{137}Cs inventory (80% from Chernobyl and 20% from bomb fallout) is about twice at Gordola (30 kBq/m²) compared to Hinterrhein (15 kBq/m²). Due to repeated floods of Ticino river, the cesium distribution at Gordola shows an important heterogeneity. Assuming an exponential distribution, the corresponding relaxation mass per unit area β in g.cm⁻² are thus higher at sites near the river (sites 11-18) partially recovered with alluvium than at furthest sites (sites 1-10). At the alpine sites of Hinterrhein the β -values are more homogeneous and indicate a weak transfer of both cesium deposits Chernobyl and bomb fallout, similar to observations obtained 3 years ago in the alpine region of Badgastein by the intercomparison exercise in Austria.

The intercomparison exercise provided a good opportunity for monitoring teams to check their mobile systems and applied methods and to compare the obtained results. Although in most of the cases the results were within an acceptable range, many sources of errors can still be reduced to gain a better reliability and comparability of environmental radiation monitoring results that have primary importance in controlling nuclear installations, in country-wide survey and in international data exchange.



CONFERENCES




SPEAKERS :

*C. Murith
O. Allen
G. Piller
M. Makarewicz
B. Heck
M. Ceuppens
M. Morichi
P. Giesen*

About the influence of topography on the accuracy of in situ measurements

J.P. Laedermann
Ch Murith
F. Byrde

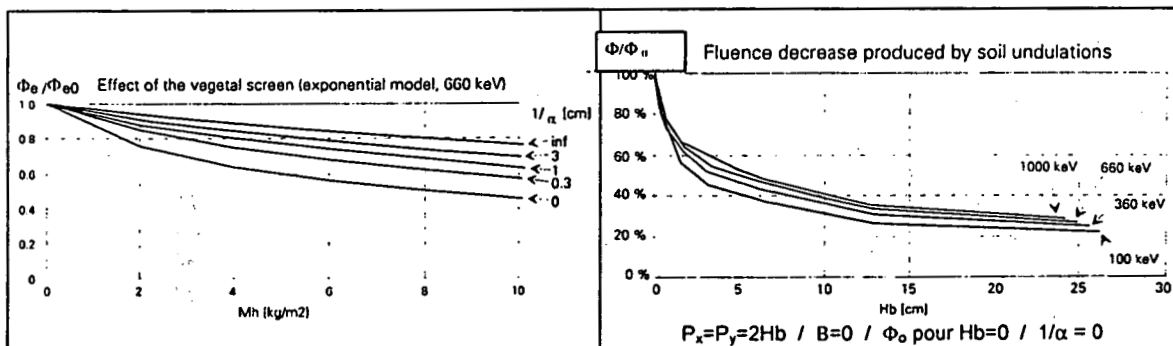
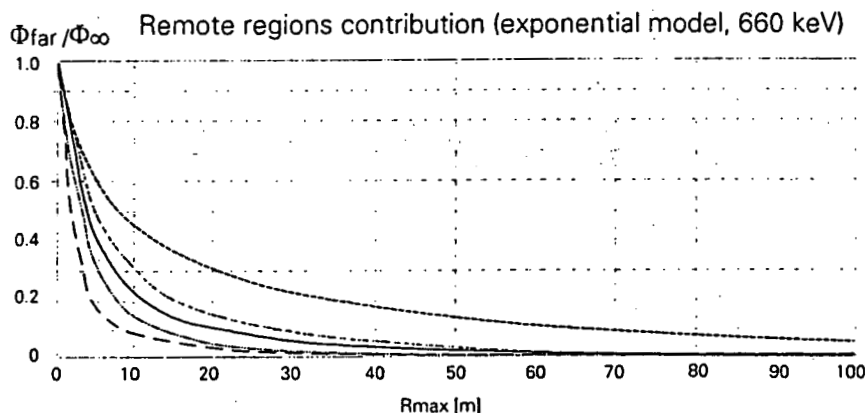
Institute of applied Radiophysic, University Centre Lausanne
Swiss federal Office of Public Health, Fribourg
NC. Laboratory, Spiez



I KNOW LOTS OF ANSWERS

BUT I'M NOT SURE THE PHYSICISTS KNOW THE RIGHT QUESTIONS

- Does the detector horizon much depend on the radionuclide distribution ?
- Does the vegetal covering affect the accuracy of the measurements ?
- Is the Influence of soil irregularities (bumps) important ?
- Must the incidence angle of the particles be taken into account ?



It stands out that, at initial stage of deposition, as the contamination is mainly on the surface, the contribution of distant regions from the detector, the ground irregularities and the vegetal covering sensitively (an order of magnitude) act on the fluence rate reaching the detector. Afterwards however, the transfer of the radionuclides in the soil switches off significantly these effects, reducing the contribution of distant regions, vegetal covering and ground irregularities.

As a result irregularities of the order of a few cm are sufficient to decrease the measured fluence by a factor of two for a surface activity, and a penetration of the nuclides of about 1 cm in soil squeezes the detector effective field from radius of 100m to 30m.

Geostatistical Mapping and GIS for the swiss soils

Artificial and Natural Radionuclides Content

O. Allen, M. Maignan, Institut de Minéralogie, Université de Lausanne, Switzerland
C. Murith, Office fédéral de la santé publique, Fribourg, Switzerland

Summary: The updated data of swiss soil contamination by radionuclides for the period 1986 - 1996 were investigated for finding out the most relevant spatio-temporal features: Network monitoring with indication of fractal dimension and Morishita index, Multivariate statistical analysis of the data set, spatial variography of the different radionuclides, Geostatistical and GIS estimation maps with display on the elevation maps, Stochastic simulation for risk mapping.

Abstract: The section for radioactivity surveillance of the swiss federal office of public health has fundamentally reviewed and updated the in situ databank of both natural and artificial gamma emitters in swiss soils for the period 1985 - 1986. All together, over 250 sites were investigated. The measurements consist of yearly determination at different locations of the natural radionuclides potassium-40 (^{40}K), uranium and thorium-series (^{238}U , ^{232}Th) and also of contamination's especially due to long term cesium (^{137}Cs) from Chernobyl, atmospheric weapon tests or local releases of nuclear power plants. The in situ procedure (measurement, calibration and calculation) is mainly based on the last recommendations of the International Commission on Radiation Units and measurements (ICRU - Report 53). The activity data were delivered as Bq/kg (natural radionuclides) respectively as Bq/m² (artificial radionuclides) with the corresponding dose rate quantities 1 meter above ground calculated in nGy/h. The geostatistical mapping confirms a good correlation between Chernobyl ^{137}Cs contents in swiss soils and rainfall quantities in the first week of may 1986. Unexpected was a correlation between natural and artificial radionuclides for every year. As an important result, the geostatistical mapping showed that a reliable representation and following throughout the year of radiological quantities need a preferential and clustered network of measurements sites.

Network Monitoring: The Network Monitoring has been described by its fractal dimension and Morishita index, in order to characterise the network spatial resolution and its ability to be representative of spatial extrapolations. The clustering of samples is very high for some years, and only a few measurements locations are homotypic from year to year

Multivariate Descriptive Statistics: In addition to basic statistical description: histograms, regressions, the principal component analysis and the automatic classification summarise the main features and the main segregation inside the data and inside the variables, with factorial axis linked to the ^{137}Cs , and then to 2 natural radionuclides, and then to the last natural radionuclide.

Spatial Correlation (Variography): The spatial correlation's with consideration of anisotropy are calculated with the variograms and modelled with appropriate functions. There are enough samples for fitting a variogram only with the background measurements, and the variograms related to the hot spots are estimated when there are enough measurements. The variogram ranges (zones of influence) lie between 53 km and 100 km.

Estimation Maps with Geostatistics and GIS: With Ordinary Kriging interpolation and display on, an atlas of estimation maps for every year for the yearly data and for the reconstituted data has been drawn. These maps are georeferenced and display also high resolution geographical features like: elevations, populated places, county borders

Conclusion and Perspectives: These geostatistical investigations, and the resulting maps as well as the GIS maps are the building stone of a more advanced study methodology using advanced methods like: IRF-k, Simulations, Artificial Neural Networks. The final goal of this is comparison and assessment of the different methods.

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Track down the Radon with Gaston



Georges Piller, Swiss Federal Office of Public Health

The rare gas radon can be found everywhere in the soil. Radon decay products are responsible for about 40 per cent of the exposition to radiation in Switzerland.

According to actual knowledge, up to ten per cent of lung cancers could be attributed to radon gas. In residential premises, it can be cited as the first of all chemical carcinogenic factors inducing lung cancer. However, various mitigation methods do exist for buildings. Regarding new constructions, preventive measures can be taken.

The studies made since the eighties showed the following results :

- Most of the radon comes from the soil and therefrom, penetrates into the houses. Neither building materials nor water are able to produce high concentrations.
- The amount of radon produced in the soil depends on its radium content. On the other hand, high radium concentrations do not necessarily present a risk regarding radon, as the latter must have the possibility to move. This specific condition is afforded by soil's gas permeability.
- A low underpressure in the house (of some Pa only) is already enough to produce an aspiration of radon loaded air from the underground to the indoor premises. Ascending air, fans, wind, and so forth, can all produce an underpressure.
- When foundations are to be built, attention must be drawn on the concrete slab which ought to be continuous in order to avoid radon diffusion.
- The more we go upstairs, the less radon concentration is to be found. Usually from the second floor, no more high values are measured.
- Isolated buildings do not show necessarily a higher indoor radon gas concentration.
- Higher indoor radon concentration can be reduced by taking suitable measures. One of the best is the combination of mechanical ventilation and a sealing isolation between cellar and residential premises. When medium concentrations are found, more simple measures are often already sufficient.
- Radon gas concentration can vary considerably from one house to the other even if they are located in the same area; differences of a factor of 100 have even been measured.
- No right forecast can be made regarding radon gas concentration for a given house; radon measurement only can bring an answer.
- Low accuracy can be given to any prediction regarding radon concentration based on geological criteria, and rules established for a given region are not necessarily applicable « as is » to any other one.

In 1994, in order to protect the population against too high concentrations, the Swiss Legislation on Radiological Protection fixed a limit value of 1000 Bq/m³. When the radon concentration in a house exceeds this limit value, the owner has to carry out the necessary remedial work. For new and reconstructed buildings, a guideline value of 400 Bq/m³ shall apply.

Nowadays, about 20'000 houses have been investigated in Switzerland. The mean value is about 70 Bq/m³ for residential premises. In 1 to 2 percent of the houses, the radon concentration exceeds the limit value. In more than 90% of the measured houses, the radon concentration is situated below the guideline value.

Regions with high concentrations were found in the cantons of Grisons and Tessin, as well as in the « Jura neuchâtelois » area. Nevertheless, values overcoming the limit value were also found on the « Plateau suisse » area. Most of the cantons are now determining the areas with elevated radon gas concentrations. This should be terminated in 2004.

Methods used by IAEA Laboratories Seibersdorf for gamma-ray measurements in remote locations.

Marek Makarewicz, IAEA Laboratories Seibersdorf.

Recently, the IAEA Laboratories participated in two missions to evaluate the radiological situation at two nuclear test sites located in the Pacific Ocean. The first mission, requested by the French government, was to Mururoa and Fangataufa atolls in French Polynesia. The mission consisted of both marine and terrestrial surveillance programmes and involved 33 scientists from 17 countries. One of the tasks of the terrestrial surveillance programme conducted in July 1996, was in-situ measurement of γ -emitting radionuclides using γ -ray spectrometry. The IAEA Laboratories used a portable high resolution γ -spectrometry system from Canberra consisting of an extended range HPGe detector (20% rel. eff.) equipped with 3 L dewar, a battery powered PC-MCA INSPECTOR, and a tripod for mounting the detector at a height of one meter above the soil/rock surface. The details of the methodology and results will be presented at an IAEA international conference to be held in Vienna during the week of 29 June 1998 (Health Phys. 73 (6), (1997) 964-965).

The second mission, requested by the authorities of the Republic of the Marshall Islands, was to Bikini Island in the Bikini Atoll (former US nuclear test site). This mission involved two IAEA staff members who conducted the mission in May 1997 (one week). Two portable 3x3" NaI(Tl) detectors were set-up on the island for screening and estimating the Cs-137 concentration in fruit and soil samples. This screening reduced the number of samples that had to be taken to the IAEA Laboratories for follow-up analysis. In addition, over 100 measurements of air kerma at the height of 1 m above ground were performed on the island, using a low-level GM-counter (model LB 1236) interfaced to the electronic unit UMo 123 from EG&G Berthold. For the measurements, the GM-tube was mounted on a standard aluminium photographic tripod.

All the instruments performed well in the high humidity and high air-salinity environment except for the two standard laptop computers which failed during the mission to Bikini. For long-term (months) or more frequent operation in a tropical or sub-tropical environment, laptops designed to function in high humidity and high salt content air should be employed to ensure reliable operation. The amount and weight of the survey equipment was optimised for the specific tasks to be done to enable an analyst to hand-carry the whole assembly even over difficult terrain (e.g. coral rock) or to not easily accessible locations (e.g. forest).



Measurement of a photon kerma rate in air in village area at Bikini Island (GPS at the left tripod leg, at the right - electronic module at the site designation).

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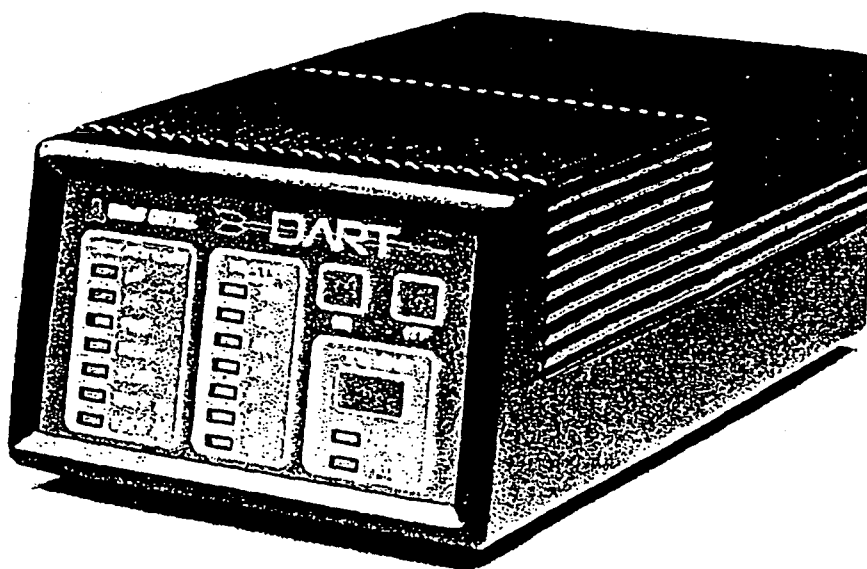
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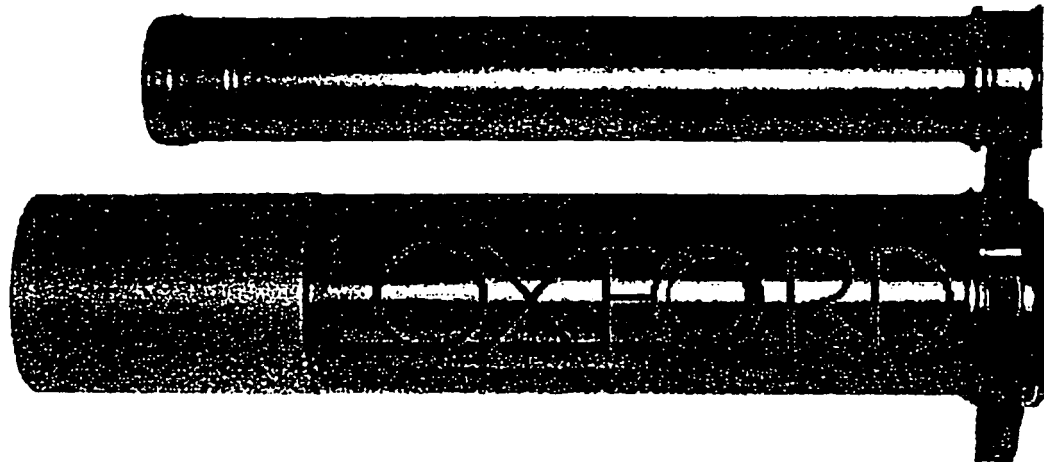
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APPLICATIONS

NUCLEAR POWER PLANTS

- Valve and Pipe Monitor
- Isotope Qualification and Quantification
- Area Monitoring
- Containment vessel monitor
- Waste Monitor

SITE REMEDIATION

- Sample Screening
- Monitoring
- Transuranic Waste monitor

SAFEGUARDS

- Verification

COMPLIANCE

- Transportation Compliance
- Scrap Metal Analysis
- Water and Air Monitoring

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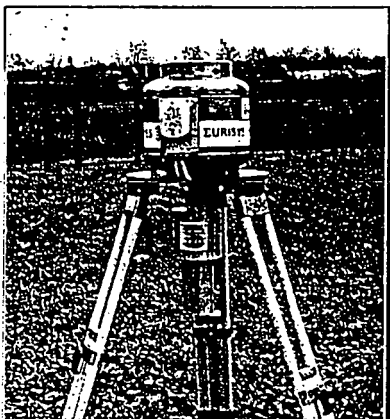
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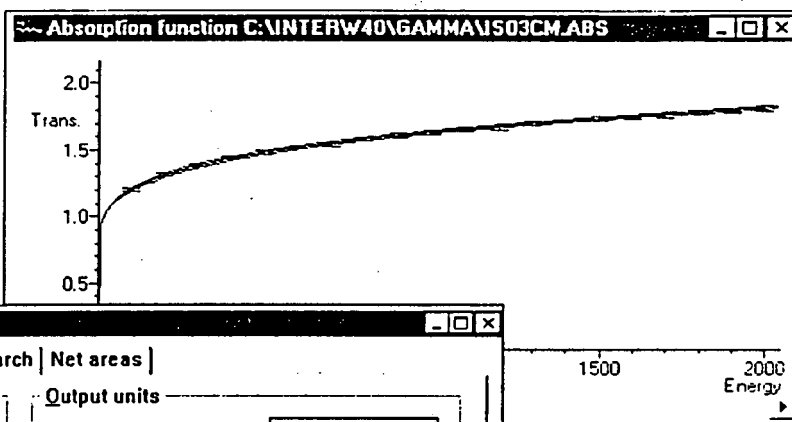
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Parameter Spectrum GORDOLA1.SPE

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Isotope table: **INSITU97** .ISO

Efficiency curve: **INSITU1** .EFF

Absorption: **ABS**

Nu1 file: **NUL**

Output file: **INSITU** .OUT

Output units

Activity unit: **Bq**

Others

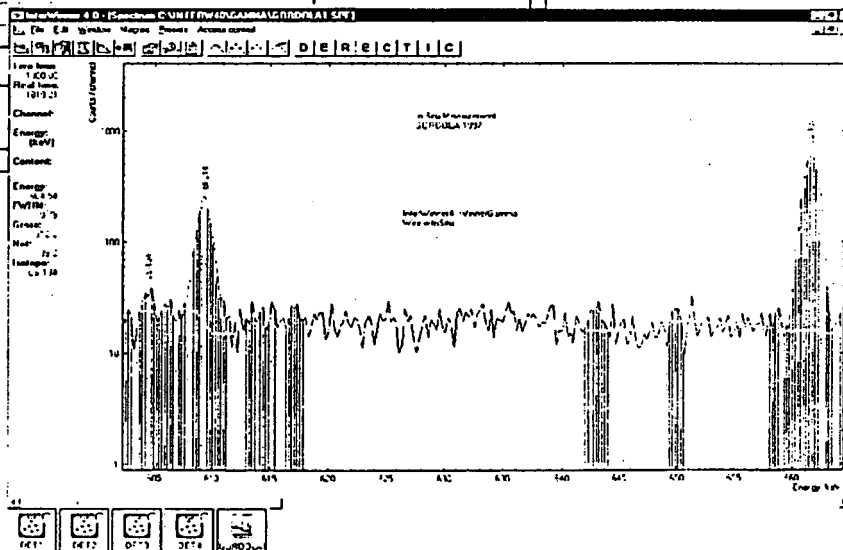
Sigma factor: **2.00**

Width of window: **0.5**

Decay corr.: **10** HLT

Data

Sample origin: **- time**



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In addition many thanks go to other sponsors especially to the pool of Swiss nuclear power plants for the famous farewell dinner in Mulin di Ciöss and to sponsoring firms EG&G, Canberra and EURISYS for their kind contribution. Without them the workshop would not have been the same.

They and all the persons involved in the success of the workshop deserve the satisfaction and positive opinion expressed by the participants.



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7. Appendix 1 : general information

Used method:

The pioneering work of Lowder et al. (1964) and of Beck et al. (1964; 1972) or „similar“ reviewed method (ICRU Report 53) represent the widely accepted in situ procedure. Especially one team used a new approach based on Monte Carlo modelling.

Detector, calibration, software:

All the teams used high-purity p or n-type germanium detectors with relative efficiency between 10 and 56% and energy resolution between 1.7 and 2.1 keV at 1.33 MeV. For the calibration, about 40% of the teams take into account the thickness of entrance window and germanium dead-layer. Although all the teams perform the measurements about 1 meter over soil with the detector facing down with the dewar overhead, 60% of them take into account angular correction factors. The common peak search software are Genie-PC and Interwinner (Intergamma), completed by own procedures.

Dose rate:

To measure the gamma dose rate in air, generally 1 meter above ground, the teams mostly used pressurised ionisation chambers and plastic counters instead of GM and proportional counters.

Numerical factors:

Table 2. Range of numerical factors used by the different teams

| Isotope | E(keV) | Emission probability $s^{-1}.Bq^{-1}$ | $\phi/A (\beta \rightarrow \infty)$ $cm^{-2}.s^{-1} / Bq.g^{-1}$ | $\dot{K}/A (\beta \rightarrow \infty)$ $nGy.h^{-1} / Bq.kg^{-1}$ |
|--------------------------|--------|--|---|---|
| ⁴⁰ K | 1461 | 0.102 – 0.107 | 0.92 – 0.97 | 0.041 – 0.044 |
| ²³⁸ U series | | | | Total |
| ^{234m} Pa | 1001 | 0.0059 – 0.0085 | 0.046 – 0.063 | 0.444 – 0.462 |
| ²²⁶ Ra | 186 | 0.031 – 0.036 | 0.12 – 0.14 | |
| ²¹⁴ Pb | 295 | 0.182 – 0.201 | 0.77 – 0.87 | |
| ²¹⁴ Pb | 352 | 0.351 – 0.393 | 1.62 – 1.71 | |
| ²¹⁴ Bi | 609 | 0.441 – 0.484 | 2.54 – 2.82 | |
| ²¹⁴ Bi | 1765 | 0.151 – 0.166 | 1.47 – 1.62 | |
| ²³² Th series | | | | Total |
| ²²⁸ Ac | 911 | 0.25 – 0.29 | 2.03 – 2.08 | 0.600 – 0.655 |
| ²¹² Pb | 239 | 0.41 – 0.45 | 1.70 – 1.86 | |
| ²¹² Bi | 727 | 0.067 – 0.113 | 0.45 – 0.75 | |
| ²⁰⁸ Tl | 583 | 0.287 – 0.309 | 1.71 – 1.76 | |
| ¹³⁷ Cs | 662 | 0.850 – 0.852 | 5.2 – 5.3 | 0.14 – 0.23 |
| | | ($\beta=0$) | $cm^{-2}.s^{-1} / kBq.m^{-2}$ | $nGy.h^{-1} / kBq.m^{-2}$ |
| | | | 0.173 – 0.176 | 2.5 – 2.8 |

As show in Table 2, they are still considerable discrepancies in the numerical factors used by the different teams, especially for the natural ²³⁸U and ²³²Th series. This source of uncertainty has to be reduced by using recently reviewed values as those recommended by the International Commission on Radiation Units and measurements in the ICRU-report 53

(tables 3 and 4). We also give in table 5 calculation factors depending on energy and distribution to estimate activity concentrations of identified radionuclides by extrapolation. The corresponding Kerma rates in air can be calculated from the data reported in ICRU-53 for about 130 relevant radionuclides. In addition table 6 gives the linear mass attenuation coefficients for the air and for the typical soil chosen for the exercise 2 (buried source).

Tables 3 and 4: Reference values from ICRU Report 53 for the natural radionuclides.

| Table 3: Photon fluence rate at a height of 1 m above ground per activity per unit mass of natural radionuclides distributed homogeneously in the ground. | | | | |
|---|--------------------|------------|---|--|
| Series | Radio-nuclide | Energy MeV | $p(E)$ s ⁻¹ Bq ⁻¹ | ϕ/A_m cm ⁻² s ⁻¹ Bq ⁻¹ g |
| ²³⁸ U | ²¹⁴ Pb | 0.295 | 0.192 | 0.828 |
| | " | 0.352 | 0.369 | 1.71 |
| | ²¹⁴ Bi | 0.609 | 0.469 | 2.75 |
| | " | 0.665 | 0.0158 | 0.0965 |
| | " | 0.768 | 0.0497 | 0.325 |
| | " | 0.934 | 0.0319 | 0.229 |
| | ^{234m} Pa | 1.001 | 0.00845 | 0.0629 |
| | ²¹⁴ Bi | 1.120 | 0.155 | 1.22 |
| | " | 1.238 | 0.0610 | 0.507 |
| | " | 1.378 | 0.0410 | 0.361 |
| | " | 1.408 | 0.0250 | 0.223 |
| | " | 1.509 | 0.0220 | 0.203 |
| | " | 1.730 | 0.0300 | 0.298 |
| | " | 1.765 | 0.162 | 1.62 |
| | " | 1.847 | 0.0216 | 0.222 |
| | " | 2.119 | 0.0125 | 0.138 |
| | " | 2.204 | 0.0525 | 0.592 |
| | " | 2.448 | 0.0162 | 0.193 |
| ²³² Th | ²¹² Pb | 0.239 | 0.434 | 1.73 |
| | ²²⁴ Ra | 0.241 | 0.0397 | 0.158 |
| | ²²⁸ Ac | 0.338 | 0.120 | 0.547 |
| | " | 0.463 | 0.0464 | 0.241 |
| | ²⁰⁸ Tl | 0.511 | 0.0809 | 0.438 |
| | " | 0.583 | 0.306 | 1.76 |
| | ²¹² Bi | 0.727 | 0.0675 | 0.430 |
| | ²²⁸ Ac | 0.795 | 0.0484 | 0.322 |
| | ²⁰⁸ Tl | 0.861 | 0.0453 | 0.313 |
| | ²²⁸ Ac | 0.911 | 0.290 | 2.060 |
| | " | 0.965 | 0.0545 | 0.398 |
| | " | 0.969 | 0.175 | 1.282 |
| | " | 1.558 | 0.0371 | 0.352 |
| | ²¹² Bi | 1.621 | 0.0149 | 0.143 |
| | ²²⁸ Ac | 1.630 | 0.0195 | 0.187 |
| ⁴⁰ K | ⁴⁰ K | 2.615 | 0.359 | 4.418 |
| | ⁴⁰ K | 1.461 | 0.107 | 0.971 |

| Table 4: Kerma rate in air at a height of 1 m above ground due to natural radionuclides distributed homogeneously in the ground (for radioactive equilibrium, of each of the radionuclides). | |
|--|---|
| Nuclide | Kerma rate per unit activity per unit mass $\mu\text{Gy h}^{-1}$ per Bq g ⁻¹ |
| ²³⁸U series | |
| ²³⁸ U | 4.33 10 ⁻⁵ |
| ²³⁴ U | 5.14 10 ⁻⁵ |
| ²³⁴ Th | 9.47 10 ⁻⁴ |
| ^{234m} Pa | 3.00 10 ⁻³ |
| ²³⁴ Pa | 4.49 10 ⁻⁴ |
| ²³⁰ Th | 6.90 10 ⁻⁵ |
| ²²⁶ Ra | 1.25 10 ⁻³ |
| ²²² Rn | 8.78 10 ⁻⁵ |
| ²¹⁴ Pb | 5.46 10 ⁻² |
| ²¹⁴ Bi | 4.01 10 ⁻¹ |
| ²¹⁰ Tl | 1.15 10 ⁻⁴ |
| ²¹⁰ Pb | 2.07 10 ⁻⁴ |
| Total | 4.62 10 ⁻¹ |
| ²³²Th series | |
| ²³² Th | 4.78 10 ⁻⁵ |
| ²²⁸ Ra | 5.45 10 ⁻⁵ |
| ²²⁸ Ac | 2.21 10 ⁻¹ |
| ²²⁸ Th | 3.44 10 ⁻⁴ |
| ²²⁴ Ra | 2.14 10 ⁻³ |
| ²²⁰ Rn | 1.73 10 ⁻⁴ |
| ²¹² Pb | 2.77 10 ⁻² |
| ²¹² Bi | 2.72 10 ⁻² |
| ²⁰⁸ Tl | 3.26 10 ⁻¹ |
| Total | 6.04 10 ⁻¹ |
| ⁴⁰ K | 4.17 10 ⁻² |

Table 5: Calculation factors depending on energy and distribution to estimate activity concentration of radionuclides in soil.

| E | Uniform | Exponential distribution ($\beta = \rho / \alpha$ in g cm^{-2}) | | | | | |
|-------|--|--|---------------|-------------|-------------|--------------|--------------|
| (keV) | $\text{cm}^{-2} \text{s}^{-1} / \text{Bq kg}^{-1}$ | $\text{Bq m}^{-2} / \text{Bq kg}^{-1}$ | | | | | |
| | $\beta \rightarrow \infty$ | $\beta = 0$ | $\beta = 0.3$ | $\beta = 1$ | $\beta = 3$ | $\beta = 10$ | $\beta = 30$ |
| 30 | 4.70 E-4 | 3.2 | 7.4 | 15 | 36 | 109 | 315 |
| 50 | 1.45 E-3 | 8.6 | 15 | 24 | 46 | 119 | 325 |
| 100 | 2.75 E-3 | 16 | 23 | 33 | 57 | 130 | 336 |
| 150 | 3.30 E-3 | 19 | 26 | 37 | 61 | 134 | 340 |
| 200 | 3.75 E-3 | 21 | 29 | 40 | 65 | 139 | 345 |
| 300 | 4.35 E-3 | 23 | 31 | 43 | 68 | 143 | 349 |
| 400 | 4.90 E-3 | 25 | 34 | 47 | 73 | 148 | 354 |
| 500 | 5.35 E-3 | 27 | 36 | 49 | 75 | 150 | 356 |
| 600 | 5.85 E-3 | 29 | 39 | 52 | 79 | 156 | 362 |
| 662 | 6.10 E-3 | 30 | 40 | 53 | 80 | 158 | 364 |
| 700 | 6.25 E-3 | 31 | 41 | 54 | 81 | 160 | 366 |
| 800 | 6.70 E-3 | 32 | 43 | 56 | 85 | 164 | 371 |
| 900 | 7.10 E-3 | 33 | 44 | 58 | 87 | 166 | 373 |
| 1000 | 7.45 E-3 | 35 | 45 | 60 | 89 | 168 | 375 |
| 1500 | 9.20 E-3 | 41 | 53 | 69 | 100 | 182 | 390 |
| 2000 | 1.07 E-2 | 46 | 59 | 76 | 108 | 193 | 403 |
| 3000 | 1.33 E-2 | 55 | 70 | 89 | 123 | 212 | 425 |

Table 6: Mass attenuation coefficients for photons in air and in a typical silty soil (data taken from nuclear science and engineering: 93, 248-261 (1986) P. Jacob and H.G. Paretzke: Gamma-ray exposure from contaminated soil).

mfp = mean-free-path of photons defined as the inverse of the linear attenuation coefficient μ' .

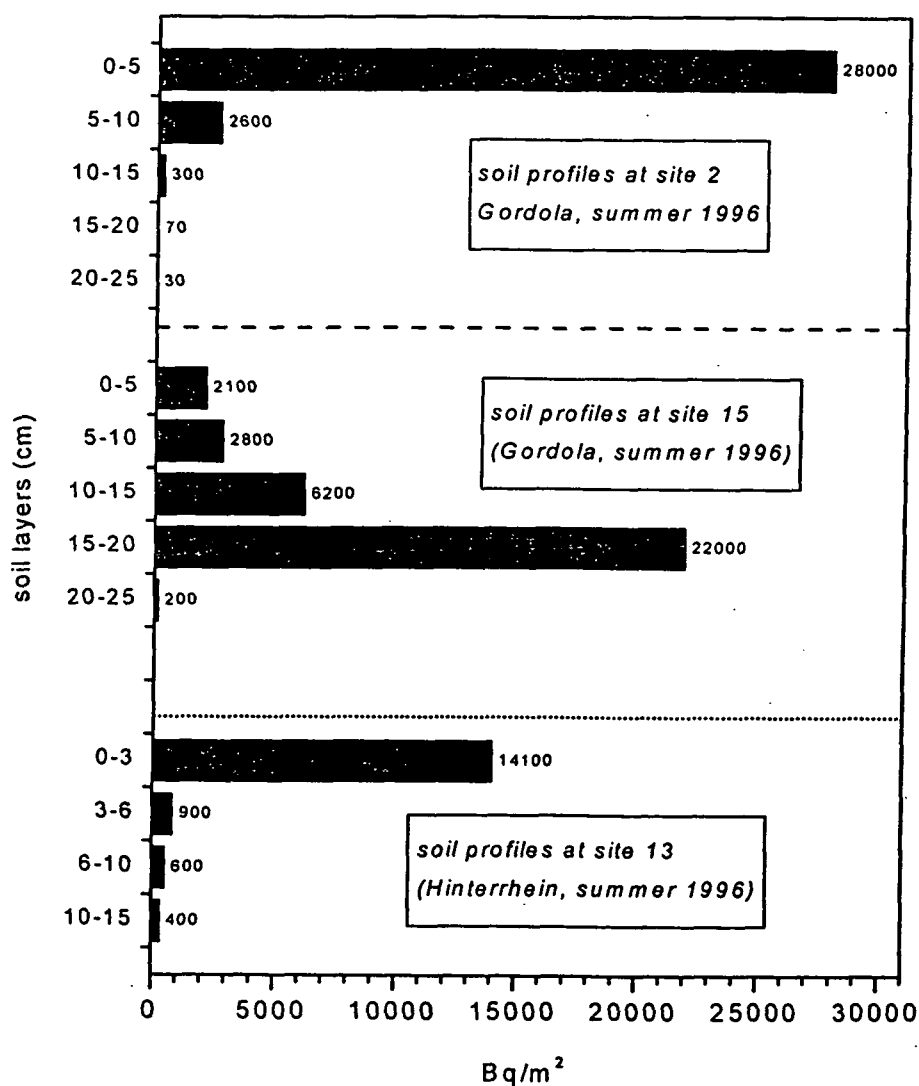
| E (MeV) | Air | | Soil | |
|------------|---|--------------|---|---------------|
| | μ' / ρ (cm^2/g) | mfp (m) | μ' / ρ (cm^2/g) | mfp (cm) |
| 0.010 | 4.748 | 1.75 | 20.39 | 0.0302 |
| 0.015 | 1.432 | 5.80 | 6.161 | 0.0999 |
| 0.02 | 0.6754 | 12.3 | 2.586 | 0.238 |
| 0.03 | 0.3104 | 26.7 | 0.8815 | 0.698 |
| 0.04 | 0.2251 | 36.9 | 0.4601 | 1.34 |
| 0.05 | 0.1935 | 42.9 | 0.3119 | 1.97 |
| 0.06 | 0.1777 | 46.7 | 0.2458 | 2.50 |
| 0.08 | 0.1609 | 51.6 | 0.1902 | 3.24 |
| 0.10 | 0.1507 | 55.1 | 0.1667 | 3.69 |
| 0.15 | 0.1341 | 61.9 | 0.1403 | 4.39 |
| 0.2 | 0.1225 | 67.7 | 0.1263 | 4.87 |
| 0.3 | 0.1063 | 78.1 | 0.1088 | 5.66 |
| 0.4 | 0.0952 | 87.2 | 0.0972 | 6.33 |
| 0.5 | 0.0869 | 95.5 | 0.0887 | 6.94 |

| E (MeV) | Air | | Soil | |
|------------|---|--------------|---|---------------|
| | μ' / ρ (cm^2/g) | mfp (m) | μ' / ρ (cm^2/g) | mfp (cm) |
| 0.6 | 0.0804 | 103 | 0.0820 | 7.50 |
| 0.662 | 0.0770 | 108 | 0.0785 | 7.84 |
| 0.8 | 0.0706 | 118 | 0.0720 | 8.55 |
| 1.0 | 0.0635 | 131 | 0.0647 | 9.51 |
| 1.25 | 0.0568 | 146 | 0.0579 | 10.6 |
| 1.5 | 0.0517 | 161 | 0.0527 | 11.7 |
| 2 | 0.0444 | 187 | 0.0454 | 13.6 |
| 3 | 0.0354 | 234 | 0.0361 | 17.0 |
| 4 | 0.0307 | 270 | 0.0320 | 19.2 |
| 5 | 0.0275 | 302 | 0.0290 | 20.6 |
| 6 | 0.0251 | 331 | 0.0267 | 23.0 |
| 8 | 0.0221 | 376 | 0.0240 | 25.6 |
| 10 | 0.0204 | 407 | 0.0227 | 27.1 |

Something about soil profiles studies.

As mentioned, soil profiles were taken and analysed in the laboratory at both examined areas. The corresponding results confirmed that the assumption of an uniform distribution in the soil for natural emitters is reasonable. As shown in following diagrams, soil profiles from summer 1996 also render observations gained from 1997 in situ measurements :

- heterogeneity of ^{137}Cs distribution at Gordola depending on the site distance from Ticino river.
- high availability of ^{137}Cs in the upper layer at Hinterrhein even 10 years after deposition.

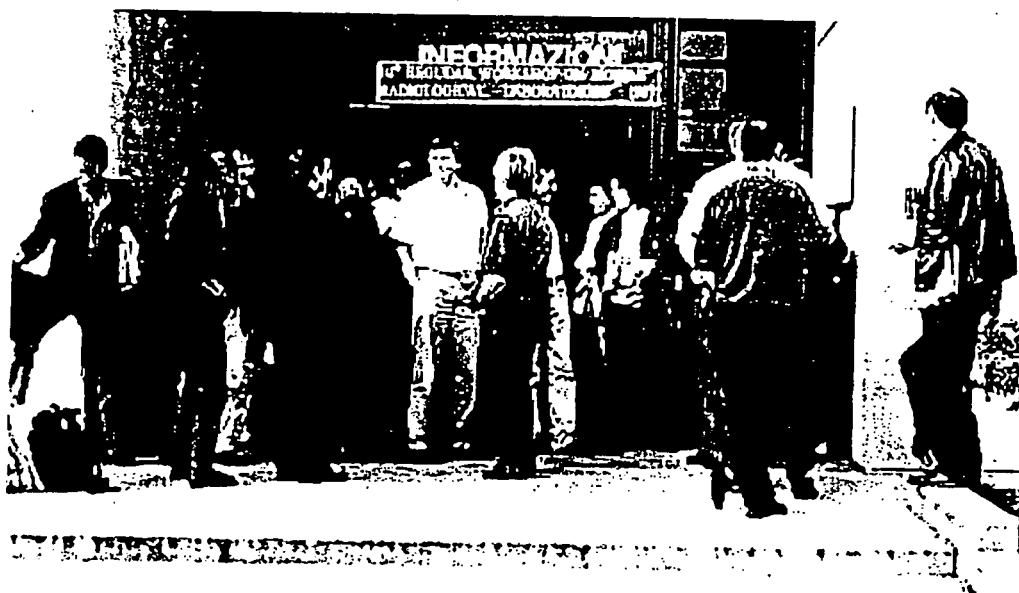
Soil profiles diagrams

8. Appendix 2 : some references

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9. Appendix 3 : LISTE OF PARTICIPANTS



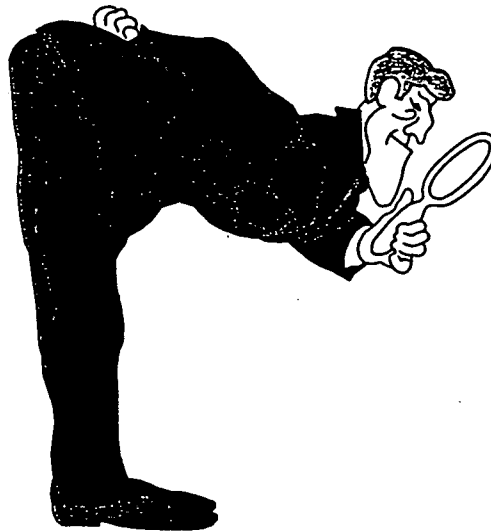
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FIRST ANNOUNCEMENT

MATHEMATICAL EFFICIENCY CALIBRATION OF GE DETECTORS FOR LABORATORY SAMPLE GAMMA SPECTROSCOPY

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Bioassay, Analytical, and Environmental Radiochemistry,
November 15-19, 1998; Albuquerque NM

The current practice in most radioanalytical laboratories is to perform efficiency calibrations with radioactive sources. From the technical standpoint, and from an economical standpoint, this is an excellent solution when water-based calibration sources are used to prepare calibrations for water-based samples. But, there are problems with this common technique, both technical and economic.

- Samples that are not water (e.g. soil, gases, vegetation, metals, ...) have different density and Z, and therefore will have different efficiencies than water.
- Chemicals can plate or precipitate out of the solution, or volatilize, and therefore have a different efficiency than intended.
- It is difficult to find calibration-quality long half-life water-soluble standards at medium energies, and at low energies and near K/L edges where many data points are needed.
- Many nuclides have coincidence summing effects and therefore are not suitable for close geometries.
- Radionuclides decay, and eventually must be replaced.

- Liquid radioactive sources require special handling and have potential contamination risks to the laboratory, but surrogates for the liquids rarely have the same response function.
- Source-based calibrations are expensive, when the cost of materials and labor are considered. These costs include source purchase, container costs, labor for calibration sample preparation, labor to perform the calibration and documentation, labor for source inventory maintenance, and source disposal costs.

Mathematical calibrations have been successfully performed in the past by several methods. Some use radioactive sources as a reference point, or as an angular response correction factor (e.g. HASL-258 for *in situ* measurement of soils), but these are not useful for close-in laboratory geometries. Some (e.g. the K-zero technique for neutron activation analysis) use mathematical formulas to compute the intrinsic response of the detector, but only work for simple geometries, and not complex shapes like Marinelli beakers. Many Monte Carlo techniques exist (e.g. MCNP, GEANT, EGS) but these are complex to program and take significant computer time. But, when properly applied, they do give excellent results.¹ While these can work fine for reference and special applications, they are not generally suitable for the ordinary radioassay laboratory.

Canberra has recently introduced a new computer program, ISOCS (*In Situ* Object Calibration Software) that allows the user to perform complete mathematical efficiency calibrations of Ge detectors. No radioactive sources are necessary, except for energy/FWHM calibrations, and this can be a single low-cost un-calibrated multi-energy point source. The original application for this calibration software has been for *in situ* counting, where the large sample size leaves the users with few calibration options, however, ISOCS is also useful for laboratory calibrations.

The ISOCS mathematical efficiency calibration software uses a combination of Monte Carlo calculations and discrete ordinate attenuation computations. At the factory, the complete dimensions of the customer's Ge detector and its mounting and housing hardware are placed into an MCNP model. Then a large number of point computations are run covering the 50-7000 keV energy range, the 0-50 meter distance range, and the 0-360 degree angular range. This large set of data is combined into a series of mathematical equations which are supplied to the user. The parameters for the equations are specific to the customer's detector, not just generic parameters. The user then selects the detector via the ISOCS software, and enters the physical dimensions and parameters describing the source and its relationship to the detector. Air temperature, pressure, and humidity are also used for attenuation corrections for spaces not occupied by the source. The ISOCS software then uses this information to compute the efficiency. This is done by a series of quasi-random source volume subdivisions. Attenuation corrections are then made for intervening source matrix, non-source attenuators like containers and air, and sample support shelves. This process is done in an iterative manner for each source volume and for each energy, increasing the number of source voxels each iteration, until the specified convergence is achieved. Although there are a great many computations, today's fast computers can do typical laboratory geometries in a few seconds.

Calibrations can be performed for many different sample shapes:

Cylindrical objects viewed from end

Cylindrical objects viewed from the side

Box-shaped objects

Marinelli beakers

Each of these objects can be located on the detector axis, or offset from it. The detector axis can be aligned with the sample axis, or at a different angle. The sample container can be of any elemental composition and density. The sample matrix can be of any elemental composition and density. The efficiency can be computed for 20 different energies from 50 keV to 7000 keV.

Validation testing of the ISOCS efficiency calibration software has been accomplished by comparing the ISOCS efficiency results with those from 109 reference efficiencies. These comparisons covered *in situ* geometries (47 tests), collimated geometries (15 tests), and laboratory geometries (47 tests). Laboratory geometries were defined as small sources closer than 1 meter to the detector, and included points, liquid scintillation vials from the end and side, larger beakers, and Marinelli beakers. The conclusion of the validation testing for laboratory geometries was that the ISOCS computation method is accurate to within 4.5% sd at high energies and 7% sd at low energies.²

These uncertainties are believed to be consistent with the errors inherent in calibrations with radioactive sources, when the calibration variables described at the beginning of this document are considered. Improvements already completed in the factory detector characterization algorithm, and are underway for a more versatile sample container algorithm to better reflect the complex shapes of the bottoms and sides of laboratory containers. These should further reduce the sd of the ISOCS calibration.

As an example of the potential errors the authors have observed in typical laboratory calibrations, consider these two cases.

- A: use of epoxy calibration standard with density of 1.15 for the assay of samples of water at density 1.0.
- B: use of epoxy soil calibration standard with a density of 1.6 for the assay of typical laboratory samples of dried soil at a density of 1.3.

Figure 1 shows the ratio of the efficiency of the calibration standard to the efficiency of the sample. The sample was a cylinder 15 cm diameter and 10 cm high, in a 2 mm thick PVC container, on the endcap of a BEGe5025 Ge detector. ISOCS was used for these calculations. These errors of 3-8% for water and 7-28% for soil can be avoided by the use of exact calibration standards, which is what ISOCS allows.

Also, consider what happens if there are small amounts of high Z materials in a sample that were not present during the calibration. Figure 2 shows the effect of the addition of a few percent of Fe in a soil sample that was not present in the calibration standard. The values are typical of Fe content in various types of soils from certain regions. Higher Z constituents have a proportionally larger effect.

Mathematical efficiency calibrations also allow the reduction of the labor involved in sample preparation. No longer is it necessary to spend time forcing all samples to fit the few available calibration geometries. No need to try to make the samples match water in density. Place as much sample as available in the counting container to maximize the efficiency. Use whatever density and composition exists in the real sample. Calibrations can be performed in a few seconds for any sample type and sample height in the container.

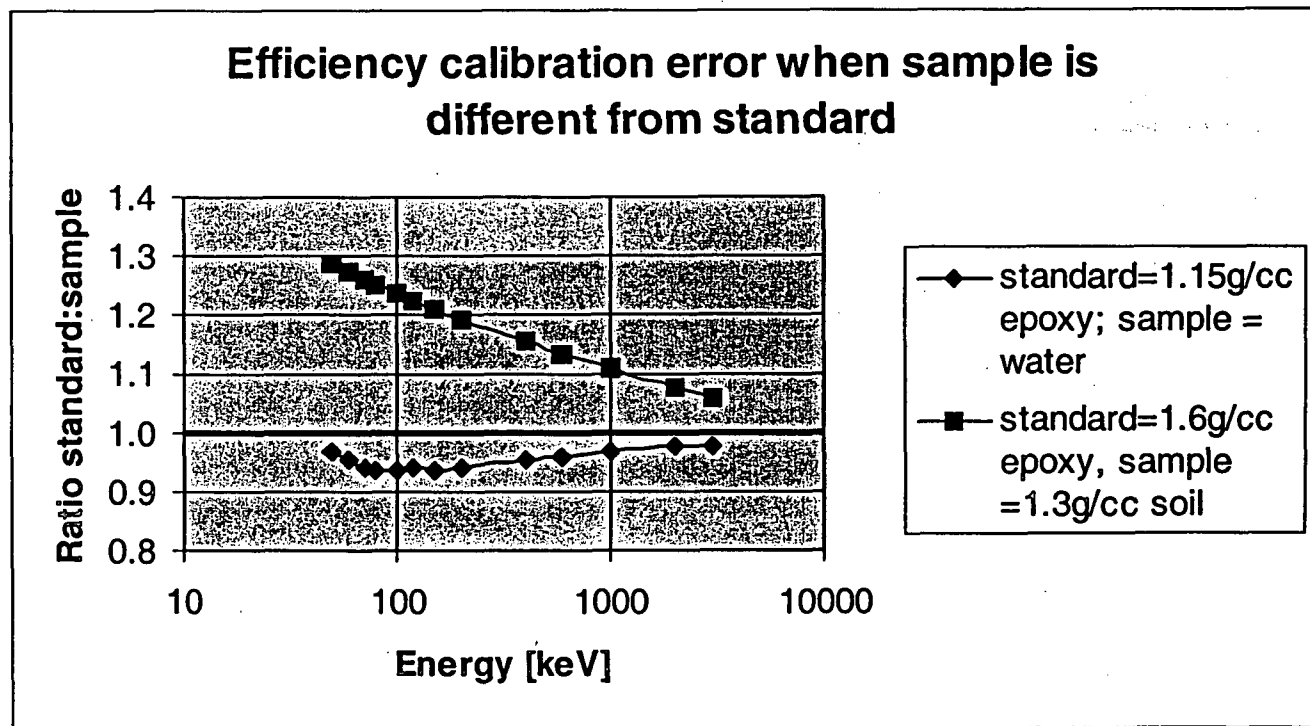


Fig 2 Efficiency calibration error vs Fe soil content

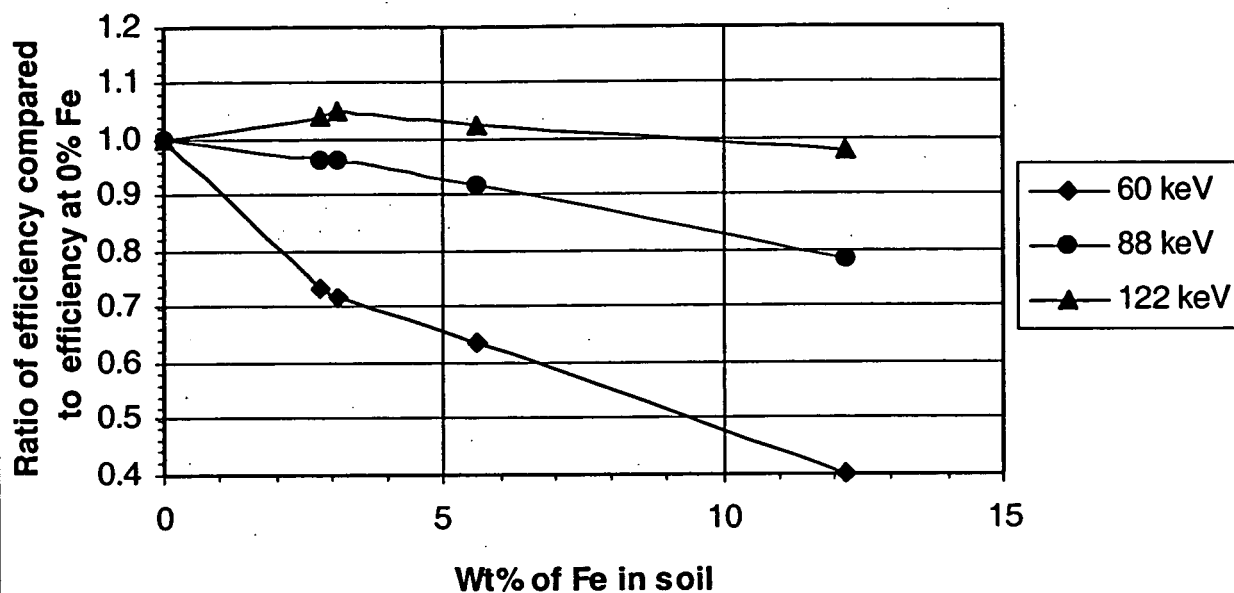


Figure 2.

Of course, a good quality assurance program is still necessary to prove to the laboratory operator and regulator that the calibrations are accurate and adequate. This includes a well designed and executed quality control program to prove that the characteristics of the detector have not changed since the characterization was done, and also includes participation in a blind proficiency testing program.

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2. ISOCS Efficiency Calibration Validation and Internal Consistency Document, ISOX-VIC 4/98, Canberra Industries, Inc. Copies available from Canberra.

OPTIMUM SIZE AND SHAPE OF LABORATORY SAMPLES FOR GAMMA SPECTROSCOPY WITH VARIOUS SIZE AND SHAPE GE DETECTORS

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Presented at the 44th Annual Conference on
Bioassay, Analytical, and Environmental Radiochemistry,
November 15-19, 1998; Albuquerque NM

Sample containers come in many different sizes and shapes. The most common are cylinders and Marinelli beakers. But, how does the analyst select the optimum container? The optimum container is generally the one that which has the best combination of detection efficiency and background for the energy of interest for the given sample size. Unfortunately, there is no single correct answer for all applications. The optimum container is a function of the sample mass available, sample density, the energy of interest, and also the size and shape of the Ge detector which will be used to count the sample.

Experimental determination of the optimum sample shape is a straightforward task, but not an easy one. A variety of containers must be constructed, filled with sources, and counted. However, today, the analyst has available versatile and accurate mathematical efficiency software, such as the Canberra ISOCSS (*In Situ* Object Calibration Software). The ISOCSS software performs these efficiency calibrations in a matter of minutes, and allows a wide range of sample container dimensions to be used. The results presented here were obtained with ISOCSS.

Ge detectors come in a wide variety of sizes and shapes. Even if the user has several detectors all of the "same efficiency" as implied by the "relative efficiency" value for the detector, the detectors are rarely the same physical size.

Relative efficiency values are computed by all Ge detector manufacturers, in accordance with ANSI/IEEE Std.325-1986. But, this value does not define

the actual detector shape. Relative efficiency is merely the efficiency at 1332 keV for a point source on the axis of the detector at 25 cm from the detector endcap face, relative to the efficiency for a hypothetical 3 x 3 in. NaI detector for the same energy and geometry.

Detectors with the same value of "relative efficiency" do not have equal detection efficiency values for other energies than 1332 keV, nor for sample shapes other than a point source at 25 cm. Ge detectors come in a wide range of diameters and heights, depending upon the detector manufacturing method, manufacturer, and the source of the Ge material. It is the physical size and shape of the active volume of the Ge, and its placement in the endcap housing that determines the true counting efficiency. So, unless the counting requirement is to assay point sources of ⁶⁰Co at 25 cm, this "relative efficiency" value is of little practical use in selecting a detector for the counting laboratory.

For this document we compare several types of nominally 40-45% relative efficiency detectors. This size represents the median size of detectors ordered, and offers good price/performance value for most applications. Three examples of Ge diameters and thickness' will be used, and are shown in the Table 1. For the purposes of this paper, they will be defined by Aspect Ratio (AR), i.e. the ratio of the diameter to the height. A Low aspect ratio cylinder has a larger height than diameter, a High aspect ratio has a larger diameter than height.

Table 1.
Detectors used for this experiment.

| Aspect Ratio | Diameter | Thickness | Volume | Comment |
|--------------|----------|-----------|--------|--------------------------------------|
| High | 80 mm | 25 mm | 126 cc | Canberra BEGe detector |
| Medium | 62 mm | 44.5 mm | 134 cc | Canberra XtRa coaxial detector |
| Low | 55.3 mm | 73.5 mm | 176 cc | Other vendor n-type coaxial detector |

For the purposes of this experiment, the internal construction of the detectors is typical for that type of detector. The diameter and thickness was adjusted so that all detectors had the same relative efficiency, as defined by the standard. These do not represent any particular detector, but the comparison between the detector types is believed to be valid.

For each of the three detectors, the ISOCS detector-specific characterization process was performed, just as if these were normal products customers ordered. Next, the ISOCS software was used to determine the sample shape with the maximum efficiency for each detector. The sample was water, in all cases. The sample volume selected for this document was 500 cc, in all cases. The sample was assumed to be within a polyethylene container 2 mm thick and located directly on the endcap of the detector.

Three different energies were considered: 122, 662, and 1332 keV.

For the 500 cc cylindrical container, the diameter and height of the sample were varied until the particular combination was found that gave the highest efficiency at each energy. For the 500 cc Marinelli beaker, the sample thickness on the side of the detector, the depth of the well of the beaker, and sample thickness on the end of the detector were varied until the particular combination was found that gave the highest efficiency at each energy. A 1 cm difference between the endcap diameter and the Marinelli beaker well inner diameter was used, to allow adequate clearance to load/unload the beaker.

The results of this experiment are presented in Table 2. The table also shows the dimensions of each optimum container.

Table 2.
Efficiency and size of optimum cylindrical container.

| Aspect Ratio | Energy (keV) | Efficiency | Diameter of container (cm) | Height of container (cm) |
|--------------|--------------|------------|----------------------------|--------------------------|
| High | 122 | 0.0513 | 11.0 | 5.26 |
| Medium | 122 | 0.0307 | 11.5 | 4.81 |
| Low | 122 | 0.0254 | 11.8 | 4.57 |
| High | 662 | 0.0137 | 11.9 | 4.46 |
| Medium | 662 | 0.0113 | 12.0 | 4.42 |
| Low | 662 | 0.0100 | 12.5 | 4.07 |
| High | 1332 | 0.00809 | 11.8 | 4.57 |
| Medium | 1332 | 0.00704 | 12.3 | 4.17 |
| Low | 1332 | 0.00674 | 12.5 | 4.07 |

Figure 1 presents the efficiency for each of the detectors graphically for the optimum container. Note that the Hi AR detector has higher efficiency for all energies, even though the Lo AR detector has 40% more mass of Ge.

Figure 2 shows graphically the inside diameter and height of the optimum cylindrical sample container. Note here, that they are all very similar, and also that they all have a high aspect ratio shape, i.e. larger diameter than height.

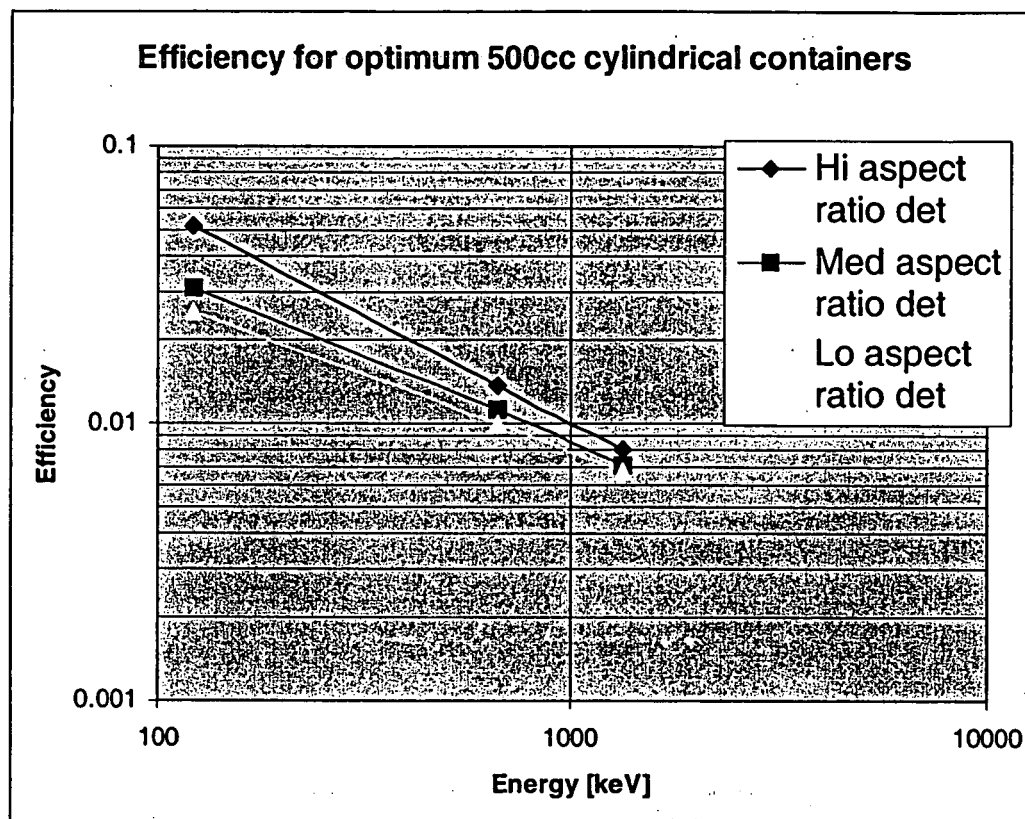


Figure 1.
Efficiency for optimum cylindrical container.

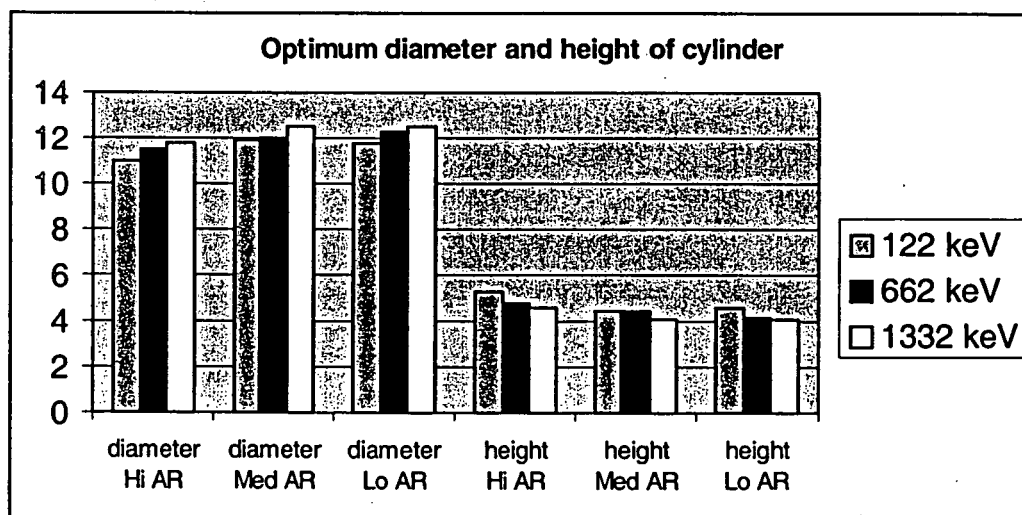


Figure 2.
Diameter and height of the optimum 500 cc sample container.

However, most users today count 500 cc samples container where the sample height is larger than the diameter, e.g. low aspect ratio. These sizes vary from laboratory to laboratory, but a typical size is approximately 7.5 cm diameter and 11.3 cm height. Using this "typical" 500 cc container, new efficiencies were calculated for each case. The ratios of the optimum efficiency to the "typical" efficiency are shown in Table 3.

This data shows that by using an optimized container, the user can typically increase the counting efficiency by 25% or more, and therefore can either reduce the

MDA by 25% or reduce the counting time by 40% of the typical values. And, there is very little difference in size between the optimum sized container for each of the three detectors, so that a common container could be used for all detectors.

Marinelli beakers are commonly used to increase the counting efficiency, but they also have an increased cost over simple cylindrical containers. As with cylindrical containers, there is an optimum size for a Marinelli beaker. The numerical efficiencies and dimensions are shown in Table 4, and graphically presented in Figures 3 and 4.

Table 3.
Ratio of optimum sample container efficiency to typical efficiency.

| Energy | 122 keV | 662 keV | 1332 keV |
|-----------------|---------|---------|----------|
| Hi AR detector | 1.27 | 1.27 | 1.27 |
| Med AR detector | 1.34 | 1.34 | 1.37 |
| Lo AR detector | 1.36 | 1.36 | 1.36 |

Table 4.
Efficiency and size of optimum Marinelli beaker.

| Aspect Ratio | Energy (keV) | Efficiency | Depth of well (cm) | Thickness at side (cm) | Thickness at end (cm) |
|--------------|--------------|------------|--------------------|------------------------|-----------------------|
| High | 122 | 0.0516 | 4.3 | 0.23 | 4.07 |
| Medium | 122 | 0.0518 | 6.6 | 1.41 | 1.69 |
| Low | 122 | 0.0509 | 8.0 | 1.40 | 0.83 |
| High | 662 | 0.0143 | 5.2 | 0.47 | 3.29 |
| Medium | 662 | 0.0174 | 6.5 | 1.39 | 1.79 |
| Low | 662 | 0.0187 | 8.0 | 1.42 | 0.77 |
| High | 1332 | 0.00847 | 5.1 | 0.49 | 3.25 |
| Medium | 1332 | 0.0105 | 6.4 | 1.38 | 1.86 |
| Low | 1332 | 0.0115 | 8.0 | 1.36 | 0.95 |

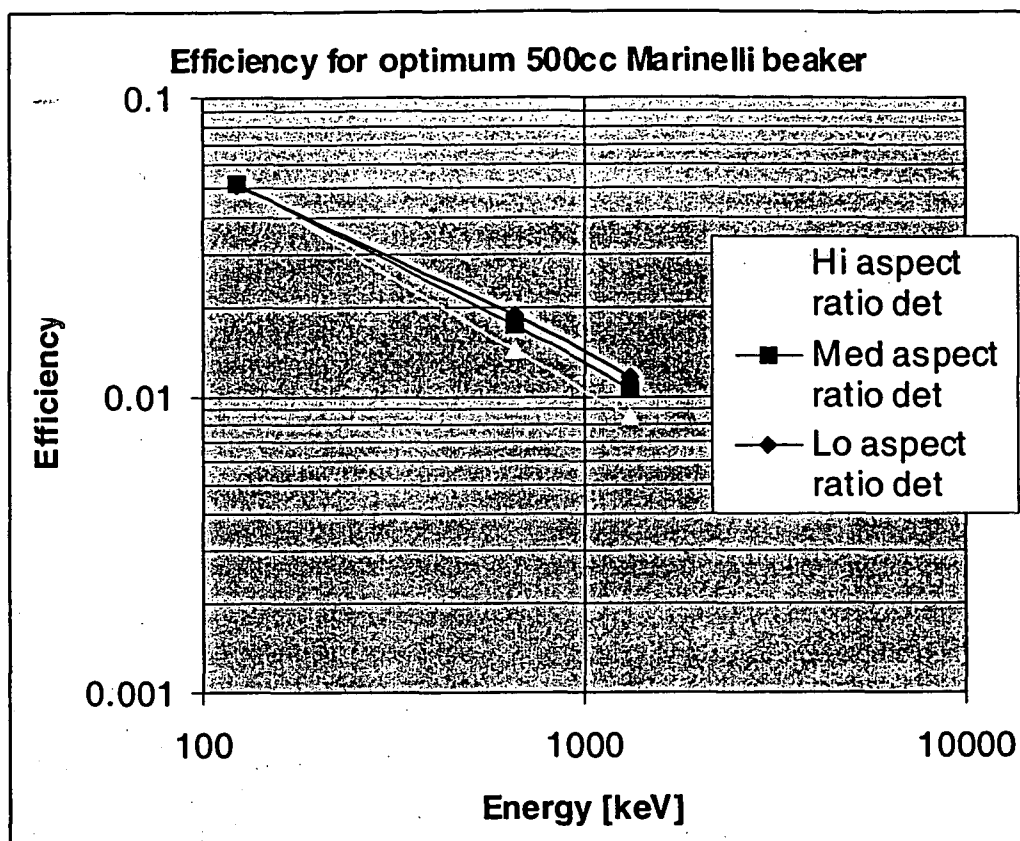


Figure 3.
Efficiency for the optimum 500 cc Marinelli beaker.

If the laboratory uses the optimum beaker size for each different detector, then all detectors have similar efficiency at low energy, but the larger volume of the Lo aspect ratio detector wins out at high energies. However, laboratory operators typically don't custom design beakers, and they don't maintain separate inventories of beakers of the same sample size. They generally purchase standard commercially available beakers, of appropriate size to fit all detectors. So, for the next part of the experiment, we used a standard Marinelli beaker that was closest to the optimum size and would fit on all detectors (Model 541G, GA-MA & Associates, Inc., Ocala FL, USA). For this beaker, the well depth was 4.6 cm, the thickness of the sample at the side of the detector was 1.1 cm, and the thickness of the sample at the end of the detector was 1.07 cm. New efficiency values were computed with ISOCS. The ratio of the optimum beaker efficiency to the standard beaker efficiency is presented in Table 5.

Table 5.
Ratio of optimum efficiency to standard Marinelli beaker efficiency.

| Energy | 122 keV | 662 keV | 1332 keV |
|-----------------|---------|---------|----------|
| Hi AR detector | 1.38 | 1.16 | 1.15 |
| Med AR detector | 1.26 | 1.26 | 1.26 |
| Lo AR detector | 1.13 | 1.14 | 1.14 |

If the optimal Marinelli beaker container is used, instead of the standard commercial beaker, an approximate 20% increase in efficiency is obtained, but at the expense of a custom design fee and probably a higher small quantity production cost. So this is not typically done.

Typical prices of standard Marinelli beakers vary depending upon quantity, size, shipping distance, etc, but are of the order of \$10 each. This is a rather significant part of the cost of performing a gamma spectral analysis. Is it really necessary? Consider

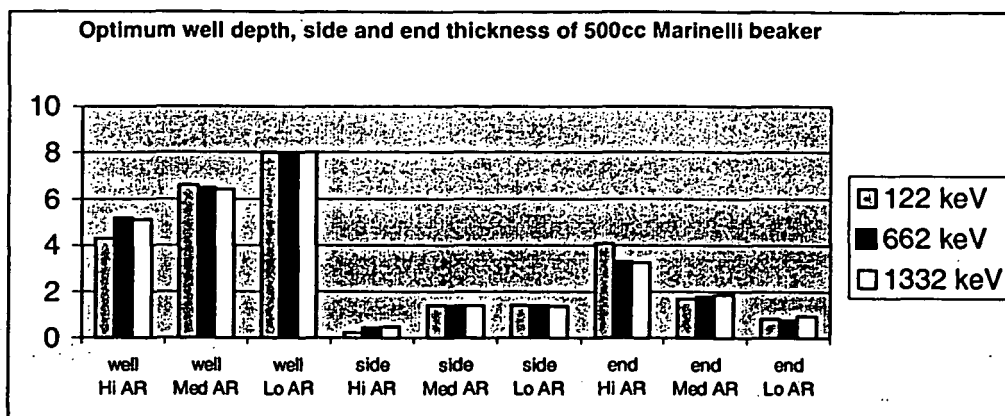


Figure 4.
Dimensions of the optimum 500 cc Marinelli beaker.

instead using the Lo AR detector with a simple cylindrical container of optimum size, instead of a non-optimum Marinelli beaker.

Table 6 presents this comparison. The Hi AR detector efficiency is that of the optimum cylinder. The Med and Lo AR detector efficiencies are for the standard Marinelli beaker. At low energies, the Lo AR detector is better by about 15% over the Hi AR detector, but at high energies it is worse by about 20%.

However, efficiency is only part of the MDA computation; background is also a part. Background is roughly proportional to detector volume, and MDA is roughly proportional to the square root of the background. Table 7 shows the relative MDAs that were

computed using this relationship. They have been normalized to the MDA of the Hi AR detector.

This data shows that the Hi AR detector using the simple optimum Hi AR cylinder has the best overall performance. There is a 30-35% lower MDA than Lo AR detector with a standard Marinelli beaker for low energy photons; the same LLD for mid-energy MDAs; and only a 6% penalty as compared to the Lo AR detector when using the more expensive Marinelli beaker. This experiment also shows the value of using the ISOCS mathematical efficiency calculation software to quickly determine these efficiency values and therefore to optimize the productivity of the counting laboratory.

Table 6.
Efficiency comparison.

| Detector | Container | 122 keV | 662 keV | 1332 keV |
|-----------------|--------------------|---------|---------|----------|
| Hi AR detector | Optimum cylinder | 0.0513 | 0.0137 | 0.00809 |
| Med AR detector | Standard Marinelli | 0.0411 | 0.0138 | 0.00833 |
| Lo AR detector | Standard Marinelli | 0.0448 | 0.0163 | 0.01012 |

Table 7.
Relative MDA comparison.

| Detector | Container | 122 keV | 662 keV | 1332 keV |
|-----------------|--------------------|---------|---------|----------|
| Hi AR detector | Optimum cylinder | 1.00 | 1.00 | 1.00 |
| Med AR detector | Standard Marinelli | 1.29 | 1.02 | 1.00 |
| Lo AR detector | Standard Marinelli | 1.35 | 0.99 | 0.94 |

MASSEMETRIC EFFICIENCY CALIBRATIONS OF GE DETECTORS FOR LABORATORY APPLICATIONS

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It is traditional in laboratory applications to calibrate gamma spectroscopy detectors in terms of absolute efficiency, i.e. counts in the photopeak per gamma of that energy emitted by the sample. Then, the sample is weighed and placed into the counting container and counted. The result is converted to concentration (e.g. Bq/g) of the nuclide of interest by the following formula:

$$\text{Bq/g} = (\text{net peak counts}) / (\text{seconds})(\text{efficiency in } c/\gamma)(\text{grams of sample})(\text{gamma yield})$$

This formulation has a few well defined characteristics.

- As the sample diameter increases, the efficiency decreases.

- As the sample thickness increases, the efficiency decreases.

- As the density increases, the efficiency decreases.

Consequently, the laboratory must prepare a different calibration for each unique combination of sample diameter, sample height, and sample density.

Following are a series of graphs. They show data computed with the ISOCS mathematical efficiency computation software. The detector used was a nominal 42% relative efficiency coaxial p-type detector.

Figure 1 shows the effect of the changing of sample diameter on the counting efficiency for several energies. The sample was water at a fixed thickness of 10 cm.

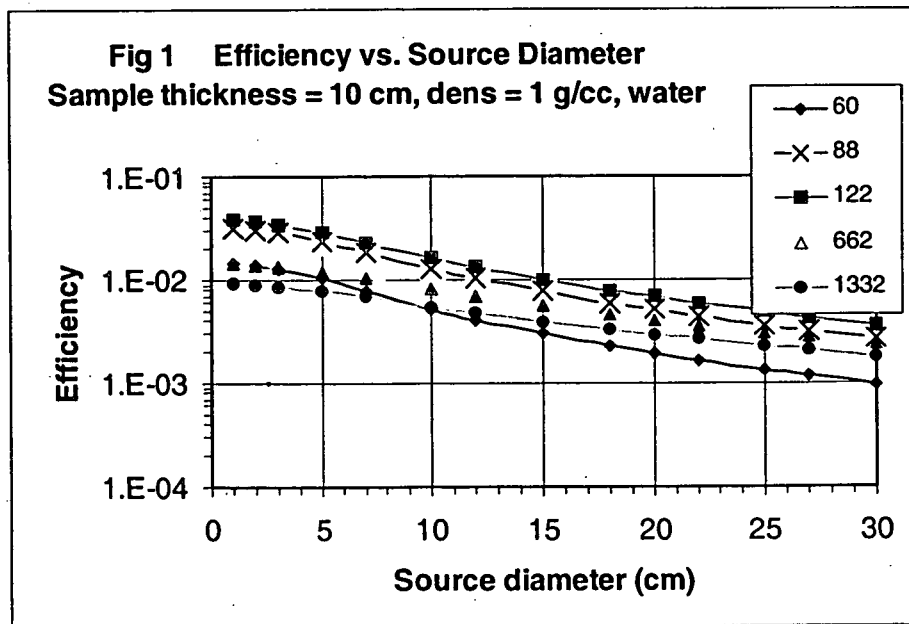


Figure 1.

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Figure 2 shows the effect of the changing of sample thickness on the counting efficiency for several energies. The sample was water at a fixed diameter of 15 cm.

Figure 3 shows the effect of the changing of sample density on the counting efficiency for several energies. The sample was water at a fixed diameter of 15 cm and a fixed thickness of 10 cm.

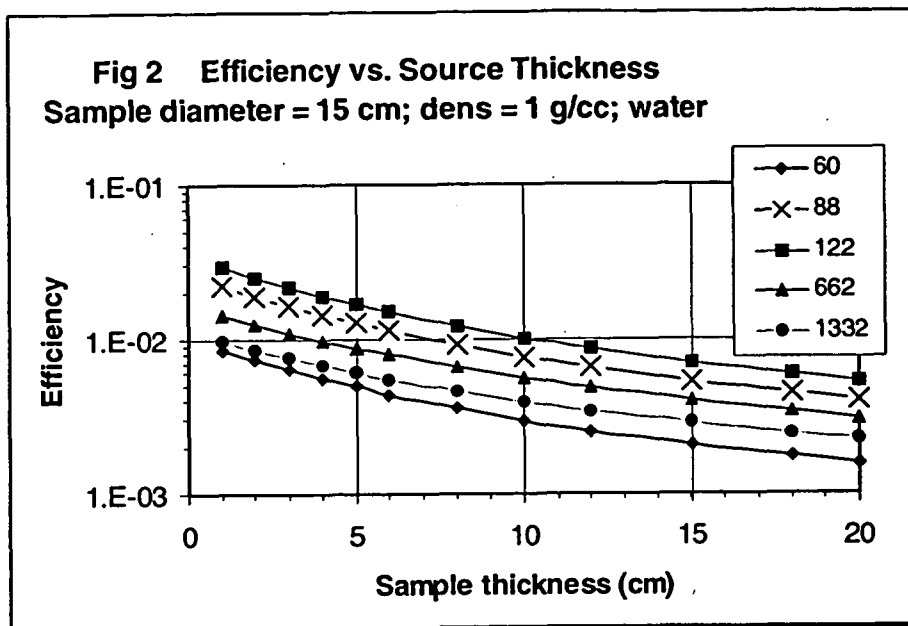


Figure 2.

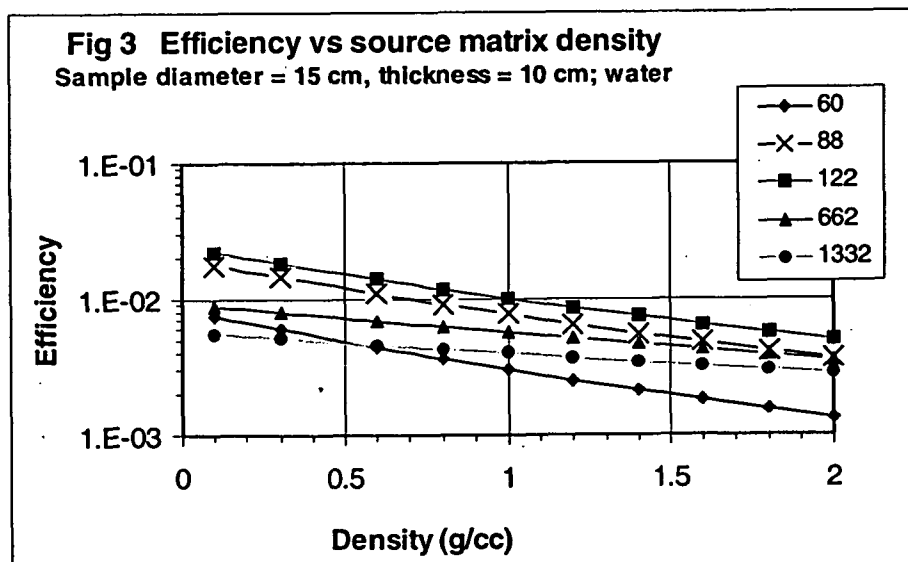


Figure 3.

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Now, consider the consequences of using massemetric efficiency calibrations. Massemetric efficiency units are in terms of net peak counts/sec per gamma/sec per gram of sample. These types of calibrations have long been used for *in situ* soil measurement applications. The counting result is converted to concentration (e.g. Bq/g) of the nuclide of interest by the following formula:

$$\text{Bq/g} = (\text{net peak counts}) / (\text{seconds})(\text{efficiency in cps/yps/g})(\text{gamma yield})$$

Now, note the changes that this method of calibration creates:

- As the sample diameter increases, the efficiency increases until it reaches a constant value.
- As the sample thickness increases, the efficiency increases until it reaches a constant value.
- As the density increases, the efficiency increases until it reaches a near-constant value.

Figure 4 shows the effect of the changing of sample diameter on the massemetric counting efficiency for several energies. The sample was water at a fixed thickness of 10 cm. The water was at zero source-detector distance. Note here, that as the source diameter gets in the 20-30 cm region, further increases in diameter have very little effect. That sample size is called the infinite diameter. This means that if you use massemetric efficiency calibrations for an infinite diameter geometry, that calibration is valid for any diameter greater than 20-25 cm. While that may not be too practical in the counting lab, it is of great importance for *in situ* spectroscopy of large objects.

Figure 5 shows the effect of the changing of sample thickness on the massemetric counting efficiency for several energies. The sample was water at a fixed diameter of 15 cm. The water was at zero source-detector distance. Note here, that as the source thickness gets in the 8-10 cm range, further increases in thickness have very little effect. That sample size is called infinite thickness. This means that if you use massemetric efficiency calibrations for an infinite thickness geometry, that calibration is valid for any thickness of water greater than 10-15 cm.

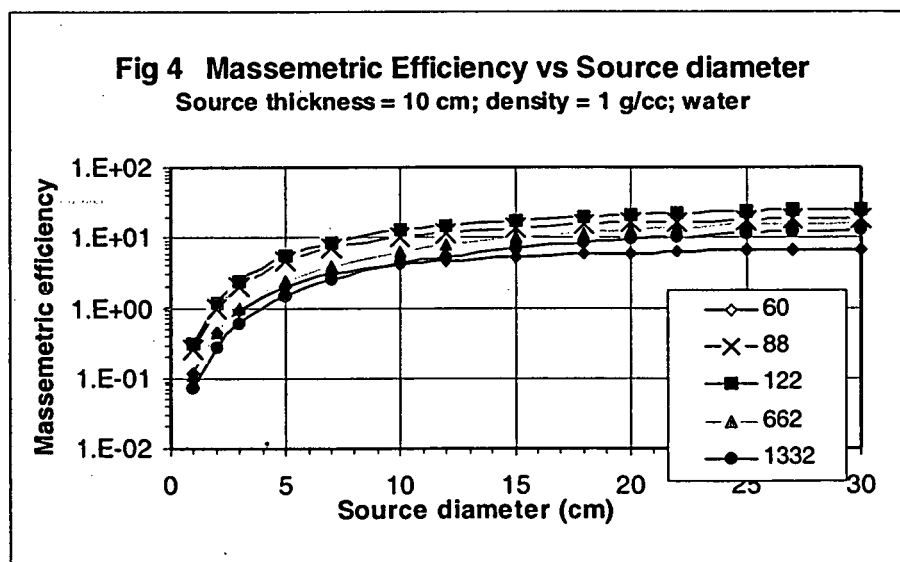


Figure 4.

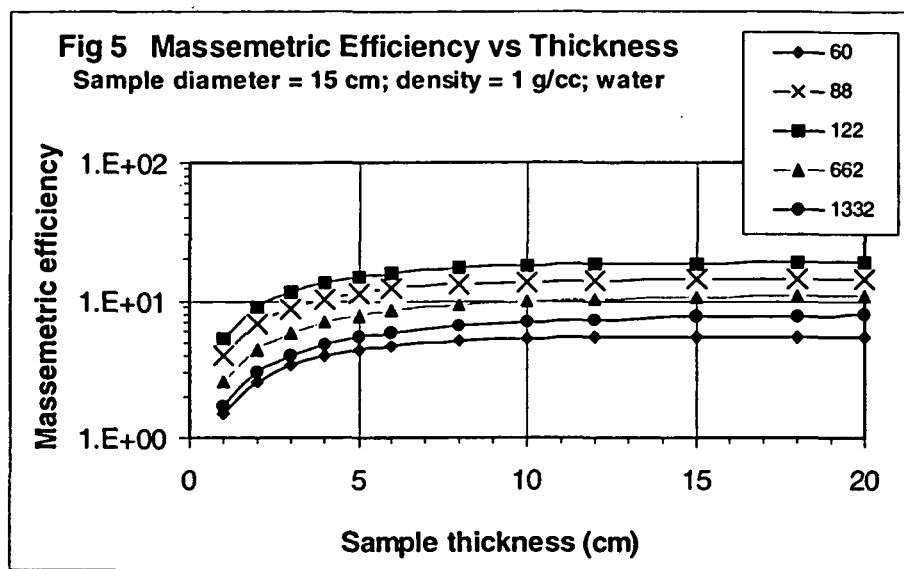


Figure 5.

Figure 6 shows the effect of the changing of sample density on the massemetric counting efficiency for several energies. The sample was water at a fixed diameter of 15 cm and a fixed thickness of 10 cm. Now, note that the efficiency does not perfectly approach an asymptotic value. There is a maximum,

after which there is a decrease. For geometries where the detector is far from the sample, as in normal *in situ* measurements, a plateau is indeed reached. At far distances, the efficiency does not dramatically change over the depth of infinite samples, but it does for laboratory geometries.

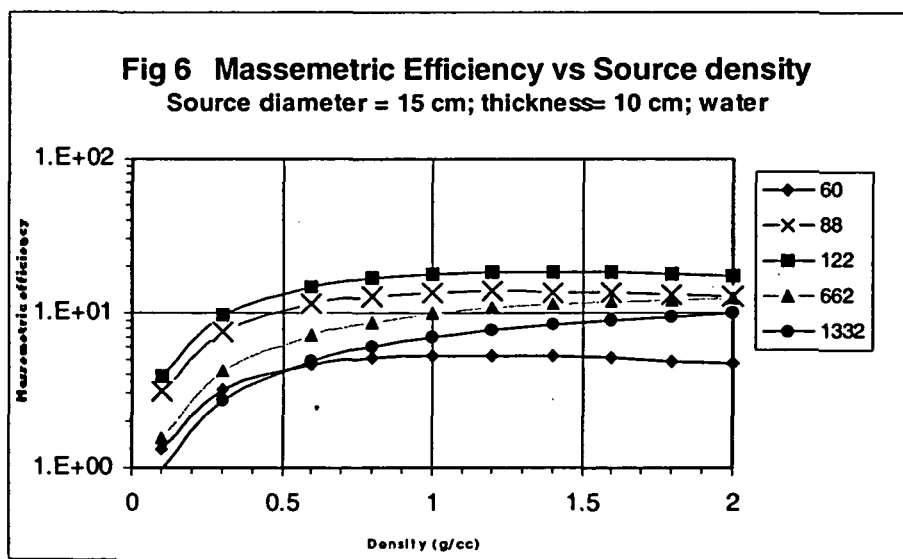


Figure 6.

The advantage of massemetric efficiency calibrations here, is that when minor unexpected changes in sample density happen, there is less of an impact on the counting efficiency, than when traditional efficiency calibrations are used.

The infinite thickness value (and also the infinite diameter value) is a function of the sample density. The higher the density the smaller the infinite thickness (diameter). Figure 7 shows the 95% infinite thickness dimension for various sample densities.

Using massemetric efficiencies and near-infinite thickness counting geometries can have both economic and accuracy benefits to an assay laboratory. Samples do not need to be weighed, saving time and recordkeeping is reduced. Sample containers do not need to be filled precisely to the same level. Just make sure that the volume is above the 90% infinite thickness level and the calibration will be within 5% accuracy, no matter what the sample height. If density varies by as much as $\pm 20\%$, the calibration accuracy will only vary by less than 5%, as long as the sample is at the 95% infinite thickness value.

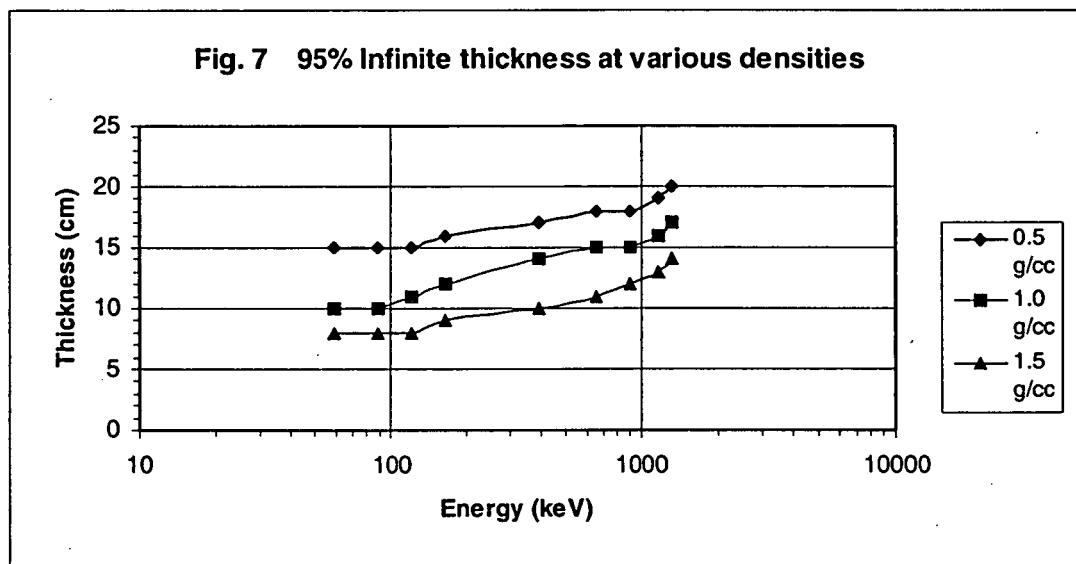


Figure 7.

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NUCLEAR INSTRUMENTATION TOOLS FOR LOWER COST AND HIGHER RELIABILITY DECOMMISSIONING OF BUILDINGS AND GROUNDS

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Introduction

The two most expensive things in the decommissioning of buildings and grounds with radioactive contamination are the labor for the contamination assessment and for the decontamination, and the cost of radioactive waste disposal. There have been many studies and papers presented on the decontamination techniques themselves, but these have been primarily about the contamination removal operation. In this paper, four new tools are presented to guide the implementation of the decontamination effort, to better characterize the radioactivity, and to reduce the volume and therefore the cost of radioactive waste disposal. A very important side benefit in this day of intense regulatory and public scrutiny is the resulting improved documentation of the radioactivity levels in the waste or other items leaving the site, and in the buildings and grounds left behind at the site.

While these tools are new, the principles behind them are not. They have been in use in quality laboratories for years. What is new is modern detectors and electronics that have made practical the transition of these laboratory quality measurements to field instrumentation.

Advances in Nuclear Instrumentation

The past 10 years have seen a very rapid growth in the capabilities and the practical implementation of nuclear instrumentation.

- Spectroscopy provides much more information about the sample and proof of the quality of the results, and is the preferred radiological assessment technique where possible.

Germanium detectors are now large enough and reliable enough to replace NaI detectors for most of these applications. Ge detectors have more definitive nuclide identification, more accurate nuclide quantification, lower detection limits, a wider dynamic range, better stability, and much higher overall confidence in the results.

- Although Ge detectors still must be cooled to operate, warm-ups cause no harm, and the cooling systems are much more practical. Efficient Dewars allow small light-weight detector packages that hold enough LN for several days of operation. Multiple-attitude cryostats allow the same detector to be used in all orientations. For long term autonomous operations, reliable LN autofill systems, and also cooling systems using gaseous refrigerants [freon-like, and Helium] are available for non-portable applications.
- A dramatic change has happened in the electronics industry. Integrated and now micro electronics have allowed the creation of full laboratory quality Multi Channel Analyzers in small totally computer controlled packages. Two such examples are Canberra's ICB NIM series for fixed instrumentation on an Ethernet network, and Canberra's InSpector which provides the same full computer control capabilities in a small lightweight battery powered package for portable applications.

- And the computers that can control these input electronics are incredibly powerful for large scale instrument operations, or very compact for portable applications. This allows extremely sophisticated software to automatically and reliably operate the instrument, analyze the data, record the results in a database, interpret the results, and then implementation an appropriate action.
- The most recent addition to this impressive evolution has been the ability to predict the performance of these instruments before they are built, and to calibrate them for quantitative analysis of radioactivity without building numerous and expensive calibration sources. Canberra has developed the use of MCNP for this, and is currently completing the development of more practical software for customer use.

Using these new tools, Canberra has developed a variety of task-specific instrumentation specifically for the contaminated sites remediation marketplace. These instruments are supplied as integrated turnkey solutions. The integration, setup, testing, calibration, and validation are already done. The customer can begin counting immediately.

Proposed Solution to Contaminated Grounds Environmental Remediation

Current practice today involves taking a large number of samples in an attempt to assess the location and the volume of the contaminated soil. For the most part, this has not been very accurate, even when large numbers of expensive samples are taken. In almost all cases, the final contaminated soil volumes are higher than the initial estimate. Current practice uses the sample results to create excavation patterns. To assure removal of all radioactive material, this excavation plan always removes more material than is really contaminated, which greatly increases the radioactive disposal costs. Current practice is to send these samples to an off-site laboratory for analysis. This is expensive, and also quite time consuming to wait for the results. Commonly, after the review of the initial sample results, more samples must be taken, and analyzed, which delays the project even more. After the excavation is complete, then more samples must be taken [and perhaps retaken] to prove that the site is clean.

Figure 1 presents two new complementary tools to provide a more cost effective and more timely solution to this problem.

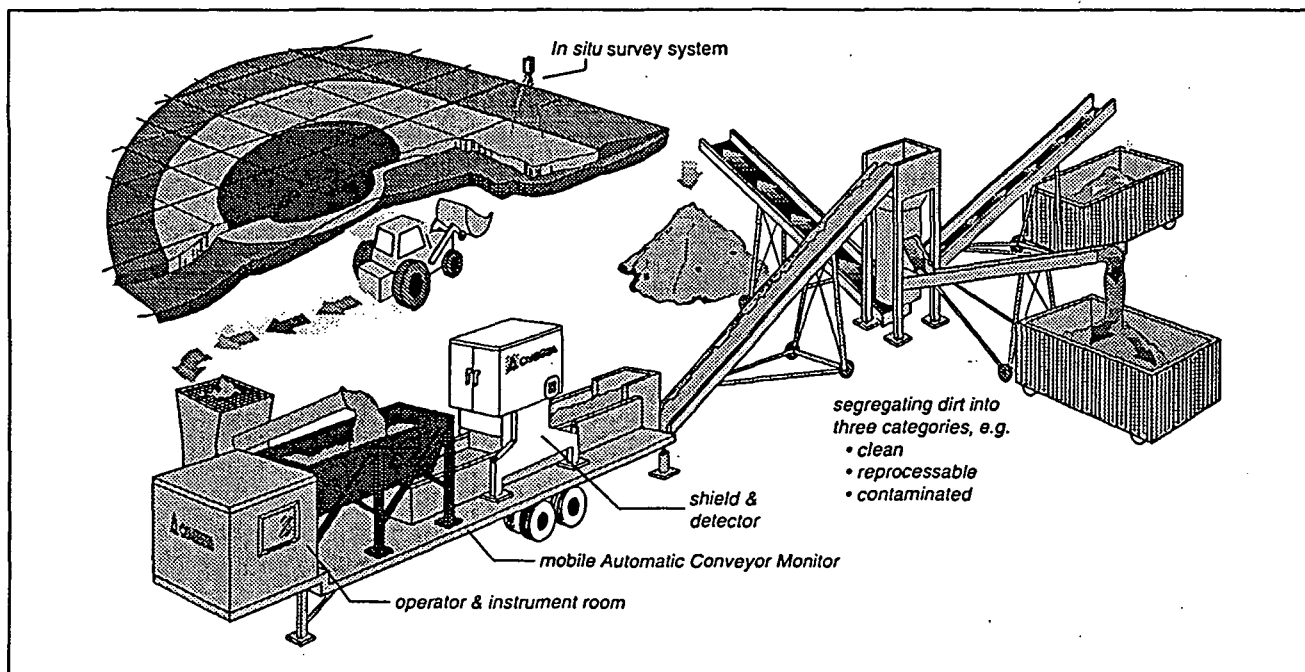


Figure 1. Instrumentation for environmental restoration.

One new tool is *in situ* gamma spectroscopy. This consists of a portable Ge detector and detector holder, portable MCA, laptop PC, data analysis software, and calibrations for the likely sample geometries. Other accessories are also available. A typical *In Situ* System can perform measurements at the 0.002 Bq/g level for most common contaminants from reactor facilities [Cs-137, Co-60] and from ore processing facilities [Ra-226, Th-232], and measurements at the levels of 0.02-0.1 Bq/g for fuel processing and reprocessing facilities [Am-241, U-235, U-238]. These are easily possible with common technology and with short [15 minute] counting times. The results are available immediately for use to determine the need and strategy for further measurements, or to guide the excavation effort. Global Positioning Systems [GPS] can be easily integrated to provide automatic sample location [latitude, longitude, and elevation] to within a meter, and to record this with the sample information. Geographic Information Systems [GIS] are commercially available to rapidly present this information to the user in a variety of cartographic schemes. The field gamma spectroscopy results can even be transmitted back to a base station via telemetry link and directly into the GIS for an immediate view of the survey effort, and to guide the selection of the next measurement point. *In situ* gamma spectroscopy can be effectively used to provide the initial site assessment, to locate the extent of surface activity to plan the next day's excavation, and to verify that the site is clean.

The second new tool is an Automatic Conveyor Monitor and sorting system [ACM] for radioactive dirt. It consists of conveyors to deposit the dirt onto the counting system, a shielded counting chamber housing two Ge detectors for sensitive accurate assay of the dirt, and a diversion system to place the effluent into one of three output streams based upon the nuclide-specific criteria for that site. Sensitivity is of the order of 0.05 Bq/g for Cs-137, Co-60, Ra-226 and Th-232. With the use of the ACM, all dirt excavated

is measured, and any that is less than the site de minimus limits can be left at the site. Soil with an intermediate activity level can be disposed at an inexpensive waste disposal site, or perhaps processed to remove the radioactivity and then be returned to the site as clean. Soil above this level is disposed as radioactive waste. Processing limits are up to 50 tons/hr at these sensitivities. Because the operation of the system is automatic, the labor requirements are minimal; therefore there is little penalty for over-excavation, as the clean dirt will be reliably separated and will not be classified as radioactive waste. Because full laboratory quality gamma spectroscopy is performed, there is no need for additional measurements of the clean effluent stream, nor of the radioactive effluent stream. Finally, the system is mobile, allowing it to be placed near the excavation site.

For a typical site, the *In Situ* System would first be used to provide a preliminary estimate of the volume of material on the site. This would be from a combination of above surface and subsurface measurements. The subsurface measurements can be most economically performed using holes drilled with well-drilling equipment and lined with plastic, and with a Ge detector placed at various locations down the hole. This volume assessment would then determine the economic applicability of the ACM. If the analysis/transportation/disposal costs are \$5000/ton, and with a decontamination factor of 50% [conservative estimate] then sites with approximately 500 tons of radioactive dirt will completely pay for the equipment through cost savings on this one week job! [note: a ton, metric ton, cubic yard, and cubic meter of loosely compacted dirt are all approximately the same] For larger sites or when an on-site engineered radioactive waste disposal cell is possible, the disposal costs are much less [commonly \$70/ton]; but even there, when the radioactivity exceeds 25,000 tons the equipment payback is complete on that one three-month job alone!

Figure 2 shows how these two instruments would be combined in a typical field operation. The *in situ* detector would be used to determine where to excavate. But since it is a surface weighted measurement, the excavations should be carried out in thin layers of perhaps 10-15 cm. The dirt would then be placed onto the ACM without mixing, which would likely increase the radioactive disposal volume. After removal of that layer, the *In Situ* System would be used again to see if the newly exposed layer of dirt is below acceptable levels. If not, dig again, and measure again until the site is clean. If other volume reduction methods like soil washing are used to process the ACM's intermediate output stream, then the ACM would also be used to verify that the soil washing output is clean.

These two tools are designed to greatly reduce the labor for the typical operation. One person can survey approximately 1000 m²/day (1/4 acre). One person

can excavate approximately the same area per day to a depth of 15 cm using a simple front end loader. And the ACM can process approximately this volume of material in a day. Because the data acquisition and analysis is automatic, then the labor to convert field samples into lab samples into analysis results into reports can also be greatly reduced.

There is also a great improvement in the quality of the job. Samples are notoriously unrepresentative if there is a non-uniform distribution of radioactivity. Unfortunately, this is typically the case for these decommissioning activities. Both *in situ* gamma spectroscopy and the ACM greatly reduce these errors by looking at a very large sample. And since the ACM looks at the entire volume of excavated dirt, the resulting assays of dirt returned to the site, and of dirt sent to the waste disposal site are also more accurate, and completely documented.

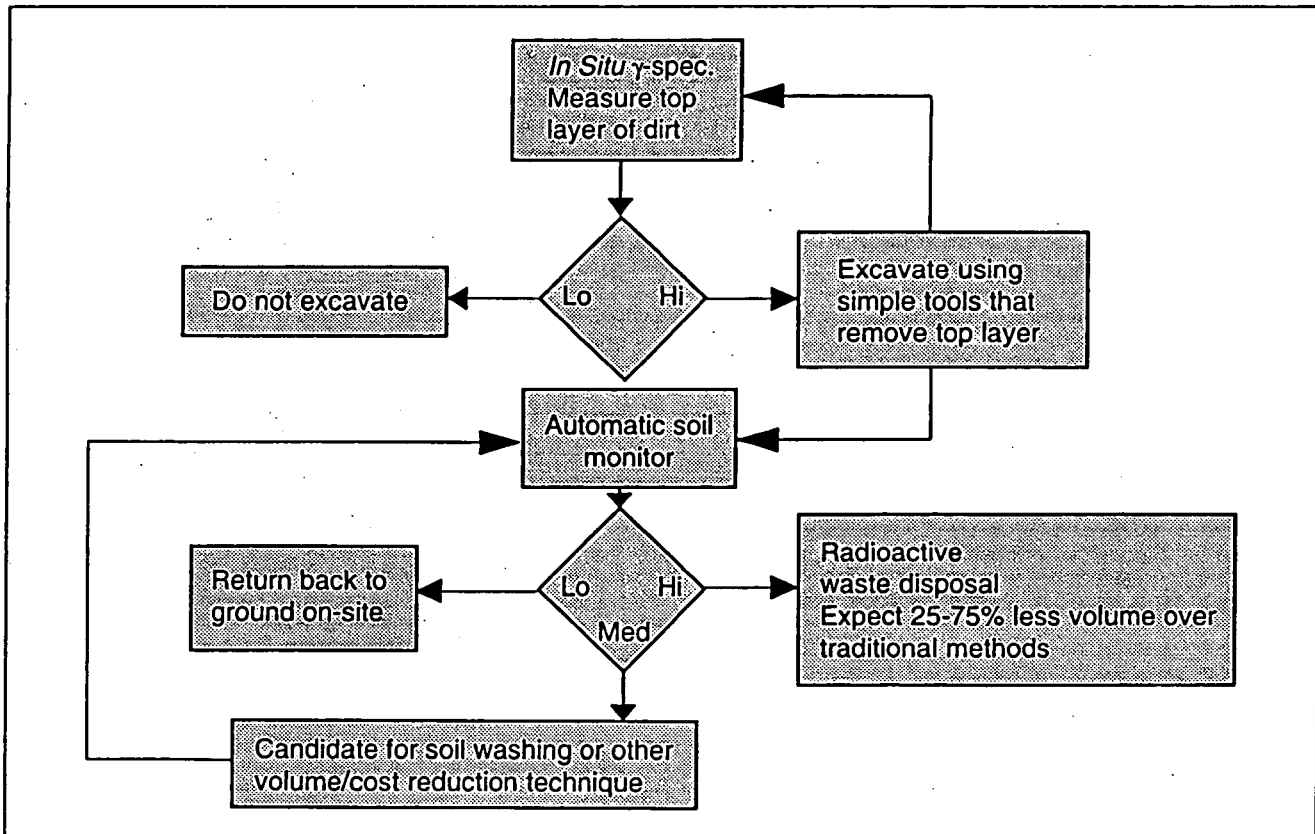


Figure 2. Flow plan for dirt environmental restoration.

Proposed Solution to Contaminated Building Decontamination and Decommissioning

This solution is a parallel one to that for environmental remediation. There is an *in situ* gamma spectroscopy tool to quickly and economically characterize the structure. Traditional decontamination tools are used to remove materials that are above site-specific nuclide-specific levels. These are placed in approved radioactive waste shipping containers [generally of a few cubic meters of size]. Those building components that are likely not radioactive, and are scheduled for removal are placed into larger containers typically used for building rubble [generally of 20-30 cubic meters]. These containers are then measured in a box counter using gamma spectroscopy to provide a final confirmatory measurement and record of the proper classification and the radioactivity level.

Current practice today involves taking a large number of samples of the building surfaces in an attempt to assess the volume and the location of the contamination. Again, this sampling process is generally not very accurate for non-homogeneous distributions. And these samples are even more labor intensive [expensive] than those of soil. Current practice uses these sample results to define areas for decontamination or for removal. Current practice is to send these samples to an off site laboratory for analysis. This is also expensive, and adds to the project time while waiting for the results. If after the review of the initial sample results, more samples are needed, then the cost and time are further increased. If decontamination is performed, then more samples must be taken [and perhaps retaken] to prove that the object is clean.

Figure 3 presents two additional new complementary tools to provide a more cost effective and more timely solution to this problem. One tool is the *In Situ* Object

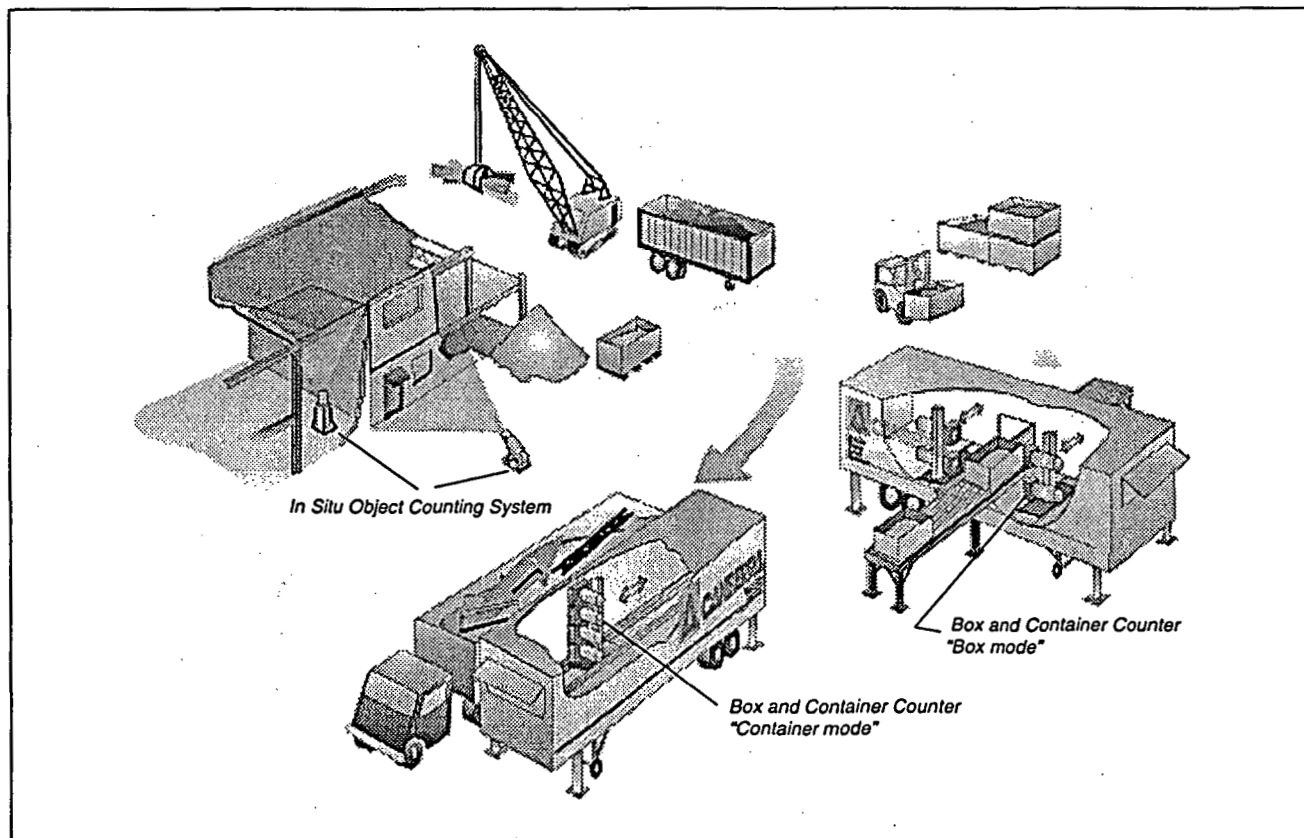


Figure 3. Instrumentation for decontamination and decommissioning.

Counter System [ISOCS] and the other tool is the Box Counter. The ISOCS consists of a Ge detector, a lead collimator and portable stand, portable MCA, laptop PC, and data analysis software. Software to compute the efficiency for the various sample geometries likely to be encountered is also included. ISOCS has adequate sensitivity to detect and quantify surface contamination on wall/floor/ceilings at small fractions of commonly used free release levels. Detection limits are in the 0.01-0.1 Bq/cm² range for Am-241, U-235, Cs-137, Co-60, Ra-226 and Th-232, with a 15 minute measurement time, for a 3 m x 3 m area. It can also be used to quantify radioactivity [or confirm the absence of it] inside objects [pumps, valves, ductwork, piping, tanks, etc.] without inherent problems associated with sampling. For these tasks, the sensitivity is generally adequate to free-release items from reactors and uranium processing facilities, and to classify as not-TRU [not alpha waste] those items with suspected Pu.

The Box Counter also uses Ge gamma spectroscopy to quantify the radioactivity in the large containers. Typically four Ge detectors would view the entire surface of both sides of each box. Multiple measurements are made vertically and horizontally to provide best accuracy and homogeneity information. The detectors automatically move to do this task. Manual systems with fewer detectors and manual placement of the detector into the appropriate position are also available for less cost, but longer assay time. With a processing time of 0.5 hour for small boxes [2 cubic meters] or 2 hours for larger boxes [30-40 cubic meters] detection limits of the order of 0.05 Bq/g for Cs-137, Co-60, Ra-226, and Th-232 are achievable.

Figure 4 shows how the ISOCS and the Box Counter would be combined in a typical field operation. The ISOCS detector would be used to determine which part of the structure was likely to be clean, and which

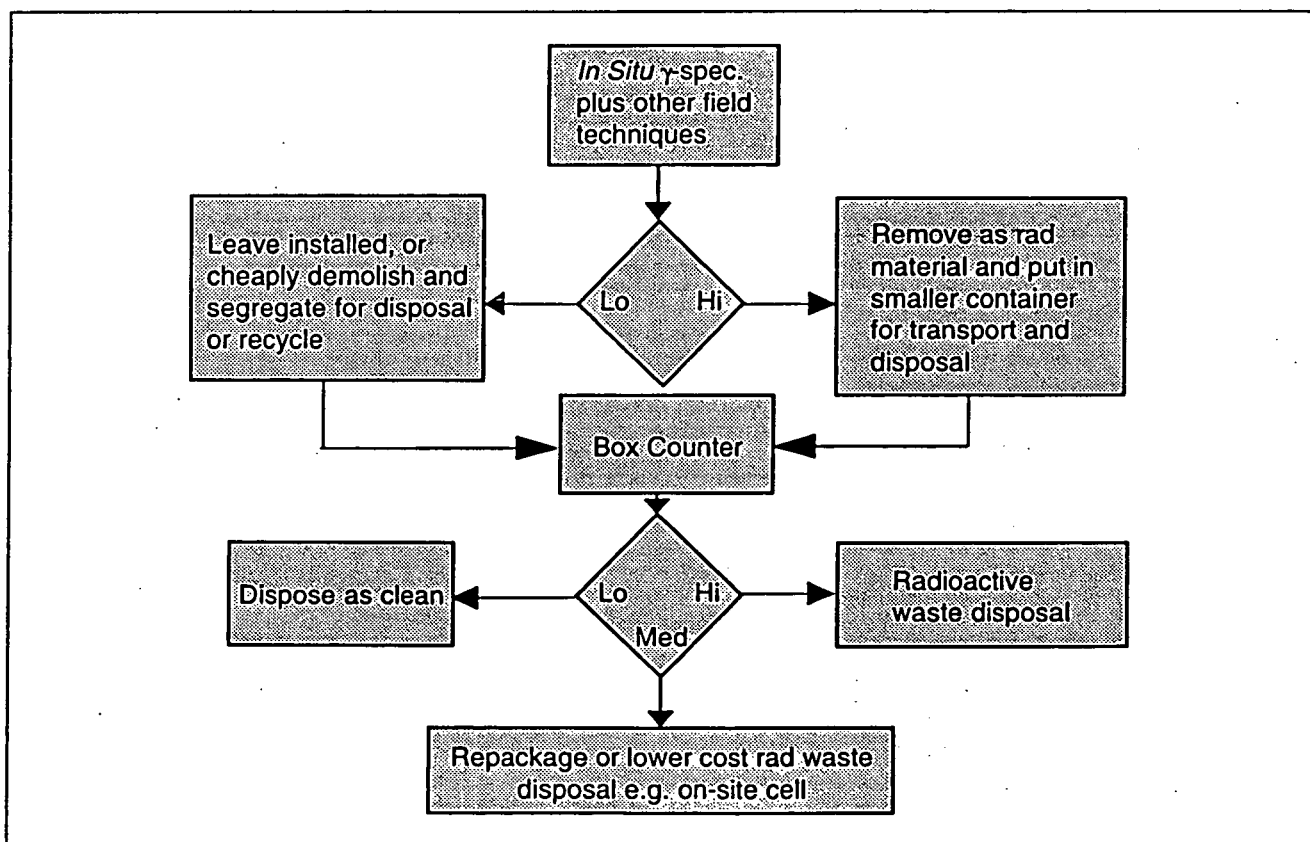


Figure 4. Flow plan of building decontamination and decommissioning.

part is contaminated. These determinations are done quickly and on a large area basis. If reuse of the building is economically feasible, then traditional techniques are used to remove the radioactivity. But commonly, demolition is the more economical choice, as then the extensive measurements necessary to prove the absence of potential contamination in pipes, sewers, and below floors is not necessary. The common use of small 208 liter drums for radioactive waste requires much labor to reduce items to small size. Cost savings will be realized if larger containers are used. Generally 2-30 cubic meter containers [B-25 boxes to ISO shipping containers] are suitable for radioactive waste transportation and disposal in many countries. The Box Counter is designed to provide direct quantitative radioassay of the contents. For heterogeneous wastes as expected here, sampling is quite error prone, and the large "effective sample size" measured by the Box Counter reduces the error bounds. This lowers the upper error bound of the radioactivity content, which generally reduces the radioactive disposal fees, and also uses up less of the disposal site's total radioactivity limit. For those portions of the building expected to be clean, very simple demolition tools can be used. The material removed is placed in large containers [roll off boxes, or ISO containers] as typical in the building demolition industry for transportation to the local sanitary landfill. But since the *in situ* characterization process was just preliminary, a final measurement of the container in the Box Counter is necessary for the definitive and official proof that the radioactivity levels are acceptable.

Like the soil remediation, there is also a great improvement in the quality of the job. Sample taking is even more error prone because of the very non-uniform nature of structure contamination. Both the ISOCS and the Box Counter greatly reduce these errors by looking at a very large sample. And since the Box Counter looks at the entire volume of building debris, shipment results are also more accurate, and completely documented.

Regulatory Roadblocks in the Way of Full Realization of the Cost and Time and Quality Improvements.

In most countries today, regulations relating to radioactivity are based instrumental capabilities that existed at the beginning of the nuclear age. They are only slowly starting to be restated in terms compatible with instrumentation available today.

Rarely is there a suitable definition of an radioactivity sufficiently low that the item can be free released. Most definitions are based upon surface radioactivity limits [$X \text{ Bq}/100 \text{ cm}^2$], and generally further subdivided into fixed and removable limits. It is difficult to discover the dose basis for such limits; they are likely based upon the instrument capabilities in existence at that time. And also, commonly, there are additional area averaging limits [e.g. the surface activity averaged over an area of 1 square meter cannot exceed X units/ 100 cm^2 , provided that no single 100 cm^2 portion exceed Y units/ 100 cm^2]. This definition makes these cost saving total activity measurement techniques described here quite impractical unless the object has a well defined surface area, and even makes conventional smear and survey meter techniques impossible unless all portions of the object's surface area are accessible. It is much easier to determine an object's weight, and it's total radioactivity. And it is more likely the total radioactivity or concentration that generally determines the object's potential for harm [dose], than surface activity.

Another example of an expensive regulatory release criteria is a "hot spot" limit. Often, volumetric release levels of $X \text{ Bq/g}$ are negotiated for soil, but with the caveat that no small volume can be greater than Y , where $Y > X$. There is very little dose related basis for this restriction, but instead the motivation seems to be making released radioactivity difficult to detect, because if you can detect it, it is bad.

Another problem stems from the lack of nuclide-specific volumetric release regulations. Current practice is to assume that things from the site are potentially radioactive, and good practice warrants screening to prove that it is not. But if something is detected, then commonly, the entire sample must be disposed as radioactive because there are no defined acceptable levels. This is a significant disincentive for the conscientious licensee to use high quality [sensitive, nuclide-specific] equipment, as it will sometimes find things that instrumentation of lesser quality will miss.

In the case where free release limits are defined using surface activity, it is acceptable for items with clearly measurable radioactivity [but less than the limits] to be free released. But, if most of the surfaces of the items are indeed contaminated to just below the limit, the radioactivity is quite large and very easily detected. In fact, this amount of radioactivity would likely be considered unacceptable for dose based release limits.

The fate of the USNRC's Below Regulatory Concern [BRC] initiative was very disappointing. It was a true dose-based limit. Its failure was a political one, not a technical one. But, perhaps there is hope for the future. It is comforting to see the IAEA and ICRP propositions of de minimus radioactivity concentrations, and the US NRC/DOE/EPA proposed risk based criteria [0.15-mSv/yr incremental dose, which can then be used to compute radioactive concentration]. But these or similar regulations are not enacted in law yet in any of the major nuclear countries.

Conclusion

Modern technology allows the creation of a new class of tools to perform reliable and practical quantitative gamma spectroscopy in the field. These devices can greatly reduce the need for sample taking and laboratory analysis. These samples and laboratory analyses can now be reduced to those necessary to establish total nuclide inventory and non-gamma nuclide correlation to gamma emitters, and for independent analyses for quality assurance purposes. This reduction in reliance on the sampling process can greatly increase accuracy for heterogeneous items. These new devices can provide more information in the official record to document the decisions made about the fate of materials released to or from the site. And, these tools can accomplish this task in a manner that saves time and money over current methodology.

GE GAMMA SPECTROSCOPY CHARACTERIZATION TOOLS FOR CONTAMINATED MATERIALS IN BUILDINGS, BOXES, AND DIRT

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I. INTRODUCTION

The most expensive items in characterization, decontamination, and release of buildings and grounds that are potentially contaminated with radioactive material are labor and radioactive waste disposal. These new instrumentation tools will reduce the labor costs, improve quality, and significantly reduce the volume of radioactive waste. The keys to this improvement are nuclide-specific instrumentation with instantaneous output, practical in-situ characterization of buildings and dirt before and during the remediation process, and high volume but low level automatic characterization of building debris in boxes and conveyORIZED dirt.

II. BACKGROUND

The techniques presented here are not new, but because of advancements over the past few years are now quite practical. High resolution gamma spectroscopy with Germanium provides much more information about the sample than gross counters or dose rate measurements. The identity and activity of each nuclide present can be determined and compared to normal levels and regulatory levels. Ge detectors are now quite portable and rugged for these field applications. Electronics, both in the Multi-Channel-Analyzer and the data analysis PC, now offer full laboratory-quality capabilities in a hand-held battery-operated package. And now we can perform mathematical efficiency calibrations for these complex objects. No longer is expensive purchase construction, and disposal of radioactive calibration sources necessary.

A. The three new DD/ER tools

Using these basic components [Ge detectors, purpose-built shielding, Canberra input electronics, GeniePC data analysis algorithms, and mathematical calibration software], we have created these tools for DD/ER applications.

The first is ISOCS [InSitu Object Counting System]. This is a portable shielded Ge detector, battery operated data acquisition electronics, with calibration and data analysis software. Figure 1 shows this device in several applications. The output is Nuclide and Activity for each nuclide. This is used to quantify activity on/in walls, floors, pipes, boxes, drums, and in/

below the ground. Typical sensitivities are generally adequate for free release. Examples are:

0.01-0.1 Bq/cm² Am241/U235/Cs137/Co60, 3x3m wall surface, 15min;

0.002 Bq/g Cs137/Co-60 and 0.02-0.1 Bq/g Am241/U235/U238, uniform soil, 15min;

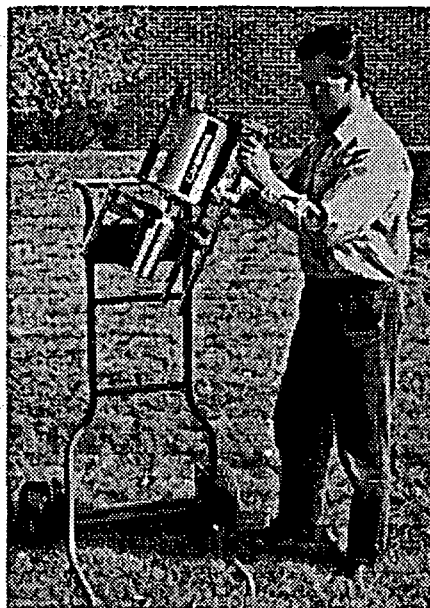


Figure 1 ISOCS measuring activity on the wall of a building and in the ground

The second tool is the ACM [Automatic Conveyor Monitor]. This unit is shown in Figure 2, and will measure and sort bulk material [dirt or pulverized construction debris]. It consists of a heavily shielded counting chamber for 1-4 Ge detectors, input electronics, analysis/calibration software, and conveyor control electronics/software. The output stream is diverted into 1-3 pathways based upon the nuclide activity. The capacity is 50 tons/hr. The first unit built had a capacity of 600 tons/hr, but that was too large for normal use. Now, because of this high capacity and low operations cost, all the dirt on a site can be assayed, which is more accurate than small samples and laboratory analyses. Typical sensitivities are generally adequate for free release:

0.05 Bq/g Cs137/Co60, dirt with normal Ra/Th/K,
50T/hr

The third tool is the Box Counter. It can measure a wide variety of box sizes and determine nuclide-specific activity. Because the entire box is measured, the results are more accurate than small samples and laboratory analysis. It consists of multiple shielded Ge detectors [typically 4] on an adjustable framework, which allows various height and source-detector distance configurations. Figure 3 shows several photographs of the individual detector towers from the manual version along with a drawing of the automatic version. The automatic version also provides computer controlled horizontal translation of the detectors along the length of the box. Boxes can range

from smaller than 1 m³ to full sized ISO shipping containers [20-30 m³]. Typical sensitivity for a 2 m³ box containing 0.6T of debris with normal Ra/Th/K:

0.05 Bq/g Cs137/Co60, 30min

B. Integrated application of the 3 tools for a DD/ER site

This example has potentially contaminated buildings with no further use, and potentially contaminated dirt under and around the buildings. First, use ISOCS for the preliminary characterization of the building. An unshielded ISOCS measurement in a room generally has adequate sensitivity to find out if radioactive sources above the release level are present. If present, find and remove most of the contaminated items. Place them into containers suitable for radioactive materials transportation, e.g., B-25 boxes. Use the Box Counter for a definitive assay of the box contents. This avoids the expense and hazard when forcing large contaminated items to fit into small drums. Since the rest of the building is likely to be clean, it can now be demolished with only minimal extra expense for radiological protection. And since the Box Counter can be used for large boxes, then minimal size reduction is needed. Place the rest of the building as construction debris into ISO containers or Roll-off boxes and use the Box counter to prove and document that it is really clean before disposition as construction debris.

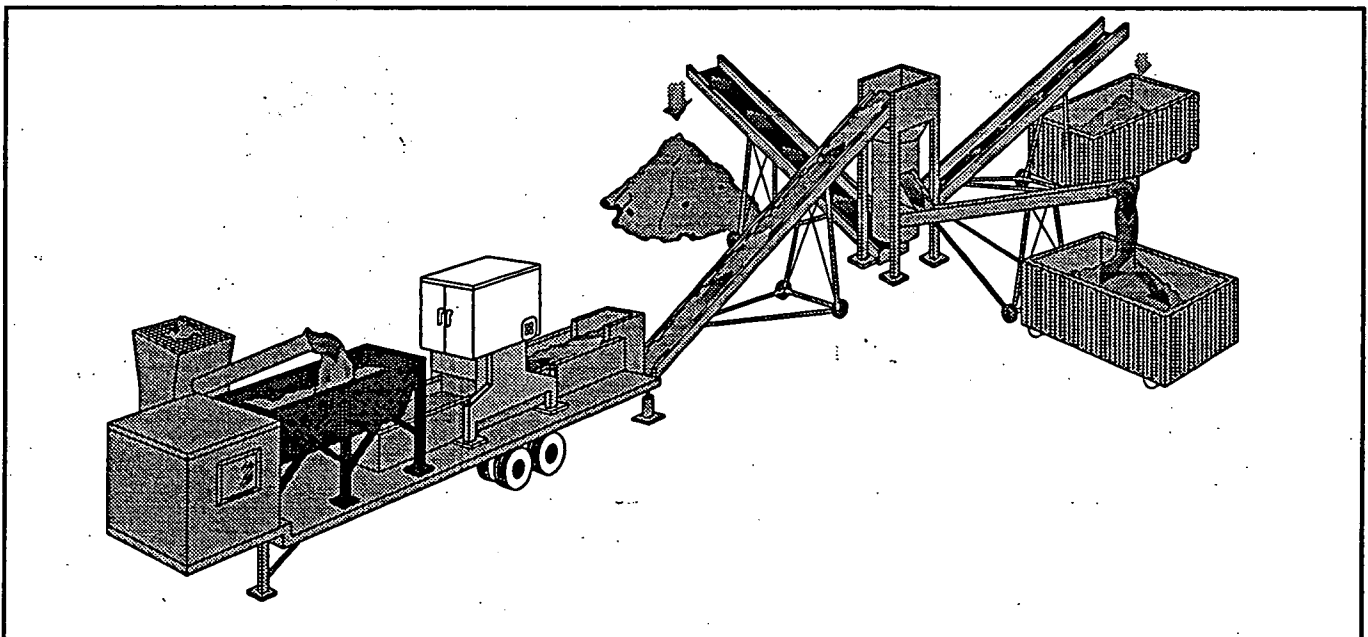


Figure 2 The Automatic Soil Monitor [v2] in a typical configuration

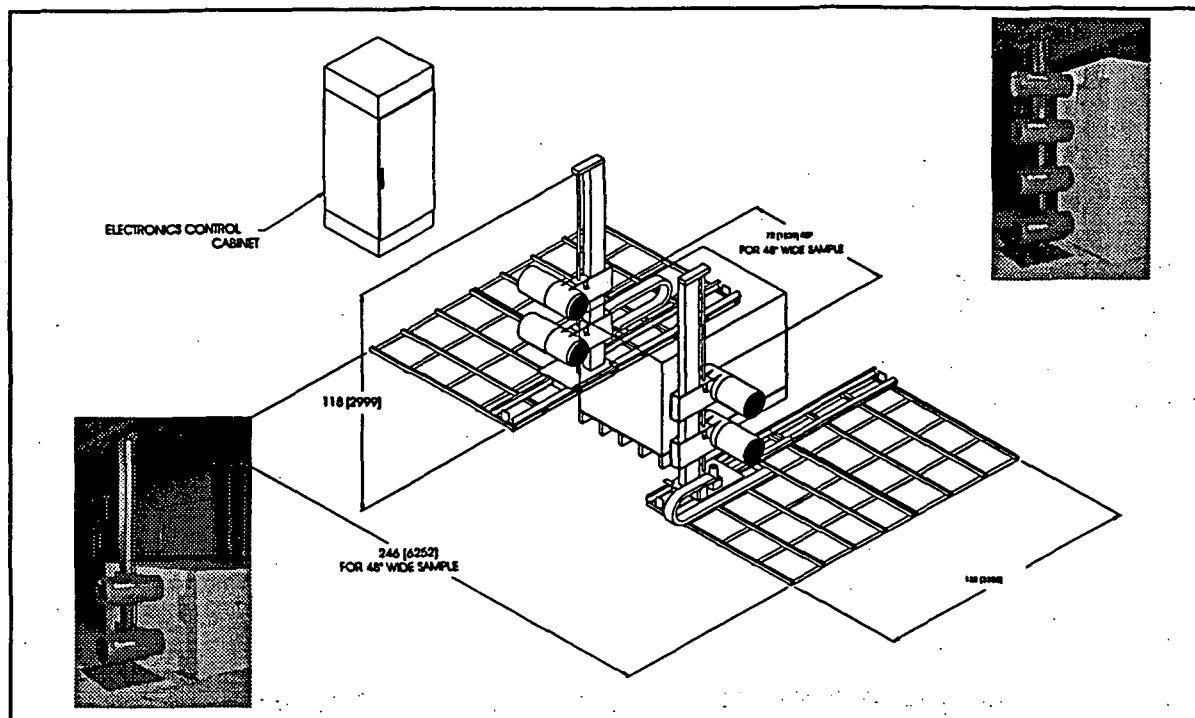


Figure 3 Automatic Box Counter [towers with 2 and 4 Ge detectors shown in photos]

The dirt is processed in a similar manner. First, use the ISOCS to define where the surface contamination is. Where contamination is present, use a simple excavation device to remove the top layer and send it through the ACM. The output will then be sorted into clean and contaminated streams [and possibly a third stream for soil washing]. Continue to measure/dig/process until all is clean. Drilled holes and subsurface ISOCS measurements can be used to verify the absence of contamination not detectable from the surface.

The use of these new tools allows much fewer expensive samples to be taken, and gives results back nearly instantaneously. The total sample analysis is more accurate than laboratory analysis of samples for non-homogeneous sources. The total sample analysis and gamma spectral data generate better documentation that the correct classification was made on materials leaving the site, or left behind. And, analyzing all potentially radioactive material with sensitive instrumentation allows much of it to be reclassified to a lower cost disposal category.

C. Regulatory Issues

To fully realize the economies from using these tools, various regulatory issues must be addressed. Many countries lack free release standards for potentially contaminated objects. Therefore, if ANY radioactivity is detected, it must be classified as radioactive. That is a disincentive to use modern highly sensitive instrumentation. Many countries lack nuclide-specific volumetric free release standards, e.g., XBq/g Co60 in dirt. Most have surface limits, e.g., YBq/cm² Cs137, but lack guidance on how to apply this to large and complex objects. Particularly troublesome are "hot spot" limits [e.g. surface activity cannot be averaged over greater than 1m²; or volumetric activity cannot be averaged over more than 20kg]. These limits do not appear to be related to dose or risk, and limit the ability to measure large volumes at one time.

However, it is good to see the US NRC/DOE/EPA near-concurrence on a proposed risk/dose based limit for residual radioactivity of 0.15mSv/y incremental. This allows volumetric nuclide-specific levels to be computed. And the recent IAEA-TECDOC-855 gives nuclide-specific unconditional clearance levels, and will hopefully be a good model for future national regulations.

Features

- Cost effective and timely radioactive characterization of the environment, facilities or equipment.
- Immediate results with professional interpretation and review.
- Utilizes state-of-the-art equipment and techniques for producing quantitative or qualitative results from numerous and unique configurations.
- Extensive expertise with *in situ* instrumentation and measurement techniques.
- Highly mobile equipment for adapting to all conditions.

Description

In situ measurements are useful methods for obtaining valid information regarding radiological contaminants in a variety of settings. In fact, in many cases, they may be the only viable means of measuring radioactive contamination. Canberra offers a comprehensive *in situ* measurement service designed to provide customers complete radiological characterization for a variety of applications.

Contaminants in the environment...

In situ measurements allow for large area or volume measurements, thereby reducing discrete sampling requirements.

Contaminants in waste...

Waste containers and materials may be assayed *in situ*, providing valuable data for disposition and disposal.

Contaminants in and on structures...

In situ measurements can support remedial action activities by providing immediate assessment of decontamination efforts.

Contaminants in systems and components...

Components such as pipes, pumps, tanks, etc. may be characterized, enabling the user to identify the source and cause of contamination.

Canberra's *In Situ* Characterization Service is ideal for those who require rapid, cost effective and site specific assistance. It will meet the needs of the client by developing site specific efficiencies and libraries for the job at hand. The client is not required to set up or learn how to use the instruments or apply the techniques since Canberra will provide a complete service. Canberra's experienced spectroscopists will collect and interpret the data without the need of the client dedicating personnel to the task.

Canberra's position as the leading supplier of gamma spectroscopy equipment and services provides assurance of reliable results. Canberra utilizes detector and geometry specific Monte Carlo Neutron-Photon (MCNP) calibration techniques to achieve highly accurate measurements without the need for collecting samples and processing them in laboratory conditions. A comprehensive report detailing and supporting the measurements is provided to document the calibrations and results.

Service

The *in situ* service meets customer needs by setting up the measurement system to address specific applications and requirements. Canberra uses a combination of MCNP modeling and verification measurements to develop calibration factors for a variety of source/detector geometries. The MCNP process has enabled Canberra to model the following :

- A point source on detector axis at 1 meter – for small, low activity objects.
- A semi-infinite plane source at 1 meter – for soil characterization.
- A semi-infinite plane source at 10 meters – for large area soil characterization.
- Walls, ceilings, pipes and ducts – for structure characterization.
- Marinelli beakers, cans, filters and cartridges – for environmental samples.
- Tank cars, bales of hay and excavations – for highly unusual situations.
- Any object which can be described mathematically can be modeled using MCNP techniques.

For Additional Information...

Call: (800) 255-6370

IN SITU APPLICATIONS EXPERIENCES GAINED IN THE USE OF ISOCS, A LABORATORY-QUALITY NUCLIDE-SPECIFIC FIELD GAMMA RADIOASSAY SYSTEM

Frazier Bronson

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ABSTRACT

Although specialists have performed *in situ* gamma spectroscopy for many years, it has been difficult to achieve quantitative results for the average user. The ISOCS instrument (*In Situ* Object Counting System) is a new integrated instrument designed specifically for this purpose. The instrument consists of a portable Ge detector, battery operated MCA and laptop computer, flexible portable shielding/collimator system, mathematical efficiency calculation software that requires no radioactive sources, and data analysis software. The user is able to identify and quantify gamma-emitting radionuclides in most objects encountered in typical DD/ER or emergency response situations.

There have been many different applications for this device. The ISOCS instrument or its predecessors have been used to show that large containers of soil were not TRU and therefore could be disposed at lower cost. Surface activity of soils was compared to traditional soil samples with good agreement. During an intercomparison exercise, Chernobyl ^{137}Cs was accurately measured, including determination of the depth profile. Also, during this exercise, the identity, activity, and depth of an unknown source were correctly determined. During a DOE demonstration contract, a variety measurements were performed, including quantifying the contents of a sealed shipping cask and contamination on the walls of a spent fuel pool. The depth/activity profile was determined in concrete without the expense of taking core samples and, a large heat exchanger was shown to not be contaminated, and thus not radioactive waste.

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INTRODUCTION

For Decontamination and Decommissioning projects, and for Environmental Restoration projects, one of the largest cost elements is radiological characterization. The need for good quality and low cost characterization is very important. Characterization is required at the beginning of the project to help scope and plan out the project. Characterization should be frequently performed during the decontamination and restoration phase as feedback to the operators about the status of the contamination after each remediation step to gauge the effectiveness of the process and to know when to stop. Characterization is also required at the conclusion of the project to document for the official record that the building/site is acceptably clean.

The traditional method for assessment of the radioactivity status of objects (tanks, pipes, drums, boxes), buildings (walls, floors, ceilings), or grounds (surface, subsurface, underwater, buried pipes, etc.) is taking samples, followed by laboratory analysis. But for areas where the contamination is not uniform (i.e. most DD/ER sites), this involves taking a great many samples. For gamma radioactive contamination, *in situ* gamma spectroscopy is less expensive than the process of taking samples, packaging and transporting them to a laboratory, and preparing and analyzing them. Previous studies^{1,2} have shown that *in situ* measurements are approximately 1/3 the cost of traditional sampling and laboratory assay for gamma radionuclides. Because the *in situ* "sample" is so large, there will normally be fewer *in situ* "samples" required. Finally, because *in situ* gamma spectroscopy offers near-immediate results as compared to

the typical days/weeks for laboratory analyses, this can have a further significant cost savings on projects and get them done more quickly.

For situations where the contamination is not uniform, *in situ* measurement techniques that assay the complete object, or assay very large portions of the object are also likely more accurate, unless a very large number of samples are taken.

In situ gamma spectroscopy has been done frequently in the past, but generally with great difficulty. Today, there are many modern advances that make this task easy. Examples include: the development of Intrinsic Germanium detectors that can warm up without damage; common availability of large Ge detectors with high efficiency; availability of rugged and reliable LN cryostats; multi-attitude operation of LN cryostats so that the detector can point in all directions; advanced micro electronics allowing small battery operated MCAs; and powerful PCs. Because of these, *in situ* gamma spectroscopy has now become a practical field tool.

THE ISOCS INSTRUMENT

Canberra has combined all of these recent technology developments and added a few more. The core equipment for *in situ* gamma spectroscopy and in the ISOCS instrument is a Germanium detector. These are available in all types and sizes to suit the needs of the applications. The Ge detector is contained in a Multi-Attitude Cryostat (MAC) that holds the required liquid nitrogen (LN). These are available in two-day or five-day holding times. The detector can

be pointed up, down, or all angles in-between. The detector is connected to a battery-operated portable Multi-Channel Analyzer (MCA), which is controlled by a laptop PC. The Genie-2000 gamma spectroscopy software fully controls the MCA and automatically analyzes the spectrum and reports the results to the user.

One of the new items to the ISOCS instrument is a flexible shielding and transport system. This is required if measurements are to be made where there are two sources present, and where one source might interfere with the measurement of the other source. The shielding comes in two different lead thickness' (25 mm and 50 mm). The lead is present at the sides of the detector, and behind the detector when the user has a detector with the RDC (remote detector chamber) option. The user may also place lead collimators in front of the detector to further define the field of view. While this item isn't *very* technologically innovative, and does not address all needs for all users, it does give the user an affordable shielding package that should cover perhaps the central 75% of the application needs.

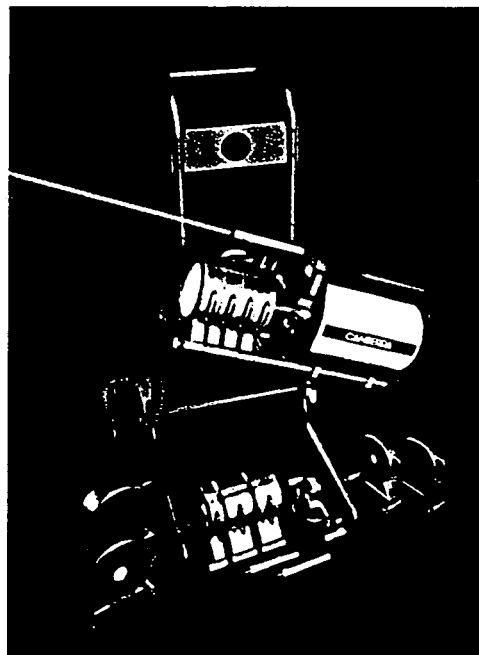


Figure 1.
ISOCS detector and shielding system.

The major technological development that makes *in situ* gamma spectroscopy a practical procedure today is the completely new ISOCS mathematical efficiency calibration software. No longer is it necessary to use radioactive sources for the efficiency calibrations for most of the common measurement geometries. The ISOCS mathematical efficiency calibration can typically be completed in a few minutes, as compared to the months to procure calibration sources, prepare them for the proper volume and density and matrix, uniformly disperse the source over a typical large sized object, and accumulate the spectrum. And, when it is time to "dispose" of this mathematical calibration source, only a "delete" key is required, rather than a waste disposal permit and a large pile of money.

The ISOCS mathematical efficiency calibration software uses a combination of Monte Carlo calculations and discrete ordinate attenuation computations. At the factory, the complete dimensions of the customer's Ge detector and its mounting and housing hardware are placed into an MCNP model. Then a large number of point computations are run covering the 50-7000 keV energy range, the 0-50 meter distance range, and the 0-360 degree angular range. This large set of data is combined into a series of mathematical equations and supplied to the user. These equations are specific to the customer's detector, not just generic parameters. The user then selects the detector via the ISOCS software, selects the collimator if used, and enters the physical dimensions and parameters describing the source and its relationship to the detector. Air temperature, pressure, and water content are also used for attenuation corrections for spaces not occupied by the source. The ISOCS software then uses this information to compute the efficiency. This is done by a series of quasi-random source volume subdivisions, and attenuation corrections for intervening source matrix, non-source attenuators like containers and air, detector shields and collimators, and other objects. This process is

done in an iterative manner for each source volume and for each energy, until convergence is achieved. Although there are a great many computations, today's fast computers can do typical geometries in a few minutes. This is commonly done during the spectra acquisition, since the times are typically compatible.

Validation testing of the ISOCS efficiency calibration software has been accomplished by comparing the ISOCS efficiency results with those from 109 reference sources. Some of these "sources" are MCNP computations, but most are real radioactive sources wherever we could find them. The problem is that it is difficult to find or prepare good quality large volume multiple energy sources of the appropriate activity range to adequately test out the model. For some of the reference efficiency values, we used the full MCNP computation method, as it has been previously shown³ to be accurate to within 5-10% for most situations. The conclusion of the validation testing was that the ISOCS computation method is accurate to within 5-10% sd, under most *in situ* measurement conditions.⁴

EXAMPLES OF FIELD APPLICATIONS

In situ gamma spectroscopy, and in particular the ISOCS instrument have been widely used to solve problems that are difficult or expensive to solve otherwise. Examples of such cases are:

U.S. DOE National Laboratory; Assay of 64 large (2 m³) boxes of soil for ²³⁸Pu

Here, the user had previously collected soil that was thought to be at a high enough level of ²³⁸Pu to be considered TRU. That creates an expensive disposal problem. Since the dirt was already in sealed B-25 boxes, sampling was rather not desirable, and would typically require expensive alpha spectroscopy. The Canberra Special Services Group (project team of Leroy Booth, CHP, and David Groff) was hired to perform *in situ* gamma spectroscopy on each of the

boxes. Mathematical techniques were used for the calibrations (full MCNP since this was before the ISOCS product release). Approximately 1/2 of the boxes were shown to be less than the TRU limit, and could then be disposed as low-level radioactive waste at a cost savings of several hundred thousand dollars.

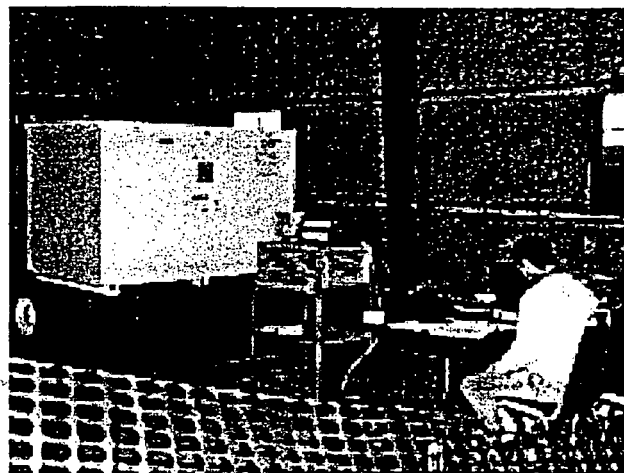


Figure 2.
Measurement of B-25 boxes for ²³⁸Pu.
Boxes were counted from multiple directions.

Measurement of surface soil activity at a FUSRAP site

This was a method intercomparison test to evaluate the applicability of *in situ* measurements as compared to traditional soil sampling and subsequent laboratory assay. The *in situ* measurements were the typical method of placing the Ge detector at 1 meter above the ground. The samples were the typical method of a series of 10 cm deep plugs. Because the area was not uniform concentration, various collimators were used for the *in situ* measurements to localize the field of view. The results indicated good agreement between the two methods, consistent with expectations given the non-uniform spatial distribution.^{5,6} The system used here was calibrated with the pre-ISOCS product MCNP01 that uses a combination MCNP and EML-258 calibration technique.

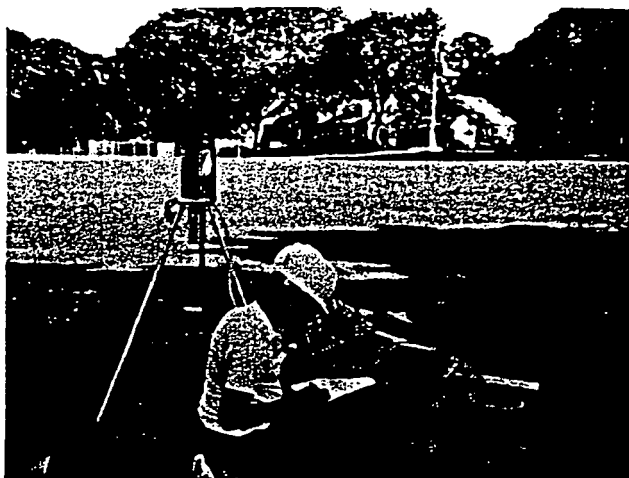


Figure 3.
In situ measurements of soil contamination.

Measurement of Activity and Depth Distribution of Chernobyl Fallout Radiocesium in a High Alpine Meadow

This was part of a European mobile laboratory intercomparison exercise.⁷ Switzerland hosted this particular one. For the official part of the exercise, they informed the participants of the vertical relaxation length of ^{137}Cs and ^{134}Cs in soil to use for reporting their results. The ISOCS system was used for the calibrations and measurements, and the Canberra team results were within the central standard deviation of the group, and consistent with the soil sampling measurements at that site. The Canberra team was Michel Ceuppens from Canberra-Belgium and Laurent Martinet from Canberra-France.

Since the vertical distribution is typically not a "given" parameter for real-world measurements, the Canberra team performed our own field investigation. Samples were taken of the top 1 cm soil layer and each cm layer below. These were analyzed by ISOCS in the field in a Marinelli beaker. The beaker counting geometry was calibrated via the ISOCS method. The field depth distribution profile was then entered into the ISOCS efficiency computation model to determine the efficiency for the detector at 1 meter above the surface. The original spectrum obtained from the detector at

1 meter above the ground was then reanalyzed with the new calibration obtained from the field depth measurements. The ^{137}Cs activity was within 3% of that of the "given" relaxation length results.



Figure 4.
ISOCS measurement of $^{134}\text{Cs}/^{137}\text{Cs}$ fallout in Switzerland.

Identification, Quantification, and Depth Determination of a Buried Source

As part of the same Switzerland exercise, a source was buried in the soil. The examinees were given 30 minutes to measure the source, and then 4 hours to determine the nuclide, the activity, and the depth of the source. After a single ISOCS acquisition, the nuclide was quickly determined to be ^{226}Ra . Because this source has multiple lines, it was then an easy task to determine the depth. A series of efficiency computations was done for different hypothetical depths. The single spectrum was analyzed with each of the calibrations. The correct calibration and depth is the one where the same activity is reported for all the energy lines of the source (low, medium, and high). Because multiple calibrations can be done very quickly, this was a very easy and fast solution. The final results were within the central standard deviation of all the participants.

Quantification of Large "Unknown" Buried Concrete Calibration Sources

Here, a series of standard calibration sources had been carefully prepared using concrete and adding radium, thorium, and potassium. These sources were 70 cm diameter, 35 cm thick, and buried in the ground with the top surface nearly flush with the ground. The ISOCS detector and shield was positioned nearly over the sources and spectra acquired. The dimensions were used to perform efficiency calibrations, which were then used to analyze each of the spectra. A blank source was also prepared, which was used to correct each of the counts of the standard sources for background activity of radium, thorium, and potassium. The final ISOCS results were within 10% of the known activity.⁴

U.S. DOE CP-5 Reactor Demonstration Project; Measurement of Contamination on Walls and Floors⁸

During this project various innovative technologies were field tested and compared against a baseline of traditional measurement methods. Large areas of concrete are contaminated with ^{137}Cs and ^{60}Co . The depth is not well known, but is suspected to be only a few mm. Various layers of paint, fabric, and other coatings cover the concrete. The ISOCS was used in the collimated mode to examine various contaminated areas. Multiple efficiency calibrations were done to show the effect of various possible depth distribution profiles. Since the ISOCS method uses gamma spectroscopy, and since both ^{137}Cs and ^{60}Co have energetic gamma emissions, the effect of the depth uncertainty on the measured activity is small. Therefore, although the actual depth profile is unknown, the use of gamma spectroscopy has results that are rather insensitive to this variable. This is unlike the reference method of beta surface counter measurements, which has a calibration factor that is very sensitive to absorbers between the source and the detector, and penetration depth into the surface.

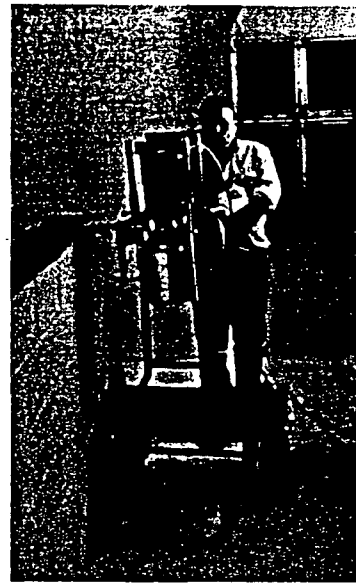


Figure 5.
ISOCS measuring floors at CP-5 Demonstration Project.

U.S. DOE CP-5 Demonstration Project; Quantification of the Contents of a Shielded Cask, and Quantification of the Activity on the Surface of the Fuel Cell Wall

Four 55-gallon drums were placed inside a shielded cask several years ago without much documentation. Therefore, it is difficult to determine the contents without extracting samples, which is both expensive and causes unnecessary exposure. The ISOCS instrument was used to measure the drum array. The detector was placed about 10 meters from the cask. Since there were other radioactive sources nearby, the collimator assembly was used around the detector to reduce the effect of the other sources. The ISOCS calibration software was used to determine the efficiency for the contents of the shielded cask.

There was also a spent fuel pool that had once contained contaminated reactor fuel elements. The next requirement was to measure the activity on the walls of the empty spent fuel pool. The detector was placed on the floor above, and aimed toward the walls of the pool. The ISOCS calibration can account for these shapes and angles; the detector does not need to

be pointed straight at the sample from the same level as the sample. All radioactive elements were removed from the pool, but at the only available detector position, the shielded/collimated detector still had interference from the shielded cask. But, since the activity of the contents of the cask were known, the amount of interference can be calculated and removed from the wall spectrum measurement.

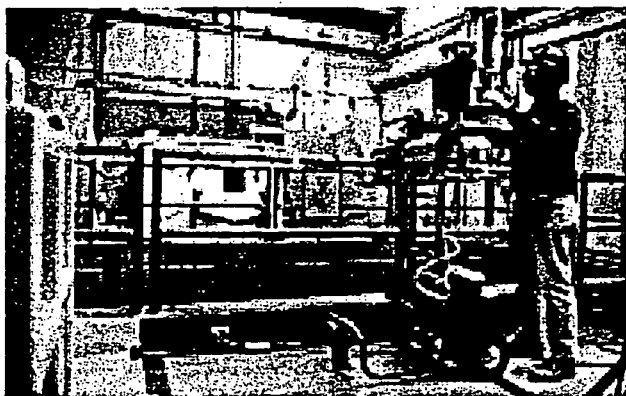


Figure 6.
CP-5 Reactor Demonstration; Measurement of shielded cask in background and spent fuel walls in foreground below the detector.

Non-invasive Determination of Activity and Depth Distribution of Activated Concrete

A neutron source from an accelerator beam had been used in a concrete room for many years. To plan the decommissioning, it was necessary to know how much concrete to remove so that the remainder would be acceptable. Traditionally, concrete core samples would be taken at much expense in labor (several man-hours per core), avoidable radiation exposure, and much elapsed time before the receipt of results (in this case several months). The collimated ISOCS was used to quickly obtain a spectrum of each area. This process was just a few minutes per sample. The activated concrete contained typical radionuclides from impurities in the concrete (e.g. ^{152}Eu , ^{154}Eu). This is fortunate since these radionuclides have many gamma energy lines at both low and high energies. Because the activation was known to be from a fast neutron source, the expected shape of the activity-depth profile in the concrete was known to be increasing somewhat at first, then decreasing exponentially.

The ISOCS calibration software was then used to create the efficiency of various activity-depth profiles in the concrete, all following the same shape, but differing in the depth profile. The spectra were then analyzed against these trail calibrations until the most appropriate one was found. The most appropriate calibration was the one where all the various energy lines from a nuclide gave the same result. These results were obtained in few days, and compared favorably to the reference method, which arrived three months later at much higher cost. Michel Ceuppens of Canberra-Benelux performed the measurements for this demonstration project.

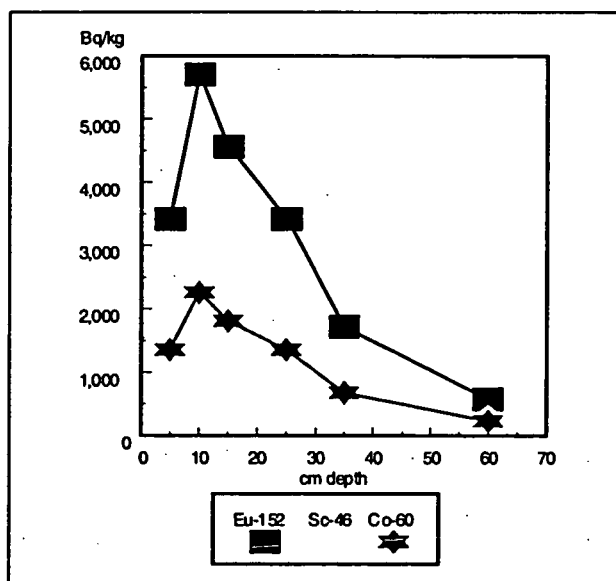


Figure 7.
Typical concentration vs. depth profile of activated concrete measurement.

Measurement of Several Large Heat Exchangers for Free Release

At the Seabrook Nuclear Power Plant, there were four large heat exchangers that had been removed from the plant. Since they were from the cold side of the plant, and were not expected to be contaminated, but it was required to prove that they were not contaminated. Previously, the removed heat exchangers were cut apart into many small pieces, so that many representative samples could be taken for field scanning and laboratory radioanalysis. The parts were placed into 20 boxes for *in situ* spectroscopy and sampling for

laboratory analyses. But that process was expensive and took a lot of time. This time, it was desired to release the heat exchangers intact. A review of water sample radiochemistry data while the heat exchangers were in service gave no indication of soluble radioactive contamination. The Seabrook ISOCS system was then used by employees Matt Scannell and Ron Thurlow to measure the intact heat exchangers. Multiple measurements were performed from various angles, and at 10 different positions along the length of each heat exchanger. Calibrations were performed with the ISOCS software. No plant-related activity was found, and the detection limits were <5% of the regulatory criteria.⁹

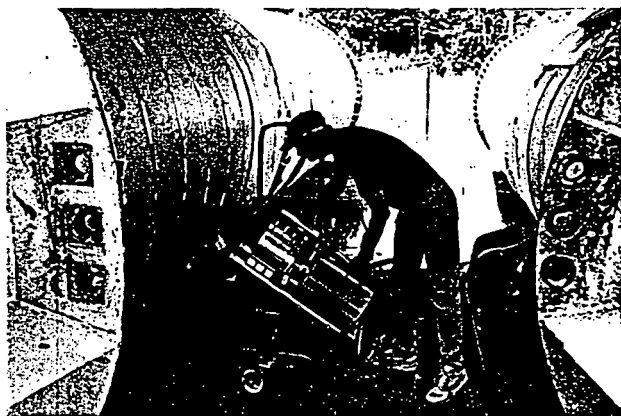


Figure 8.
ISOCS used to measure radioactivity in one of four large heat exchangers.

Underwater Measurements with ISOCS

Livermore National Laboratory procured special ISOCS systems for ultimate use by the Russian government. LLNL personnel Drs. Radoslav Radev and David Hickman performed multiple tests on the system to test the underwater integrity, and to test the calibration accuracy.¹⁰

The detectors are contained within a special underwater housing for protection. A waterproof cable and vent line goes to the surface where the MCA and PC and user are located. A special version of the ISOCS software was developed for this application. The user can define the fluid inside the housing (generally air) and outside the housing (generally water). The two

fluids fill all spaces not defined by the ISOCS calibration model.

Calibrations were performed against a 3000 Ci ⁶⁰Co irradiation source in an underwater pool at LLNL. The calibrated ISOCS measurements satisfactorily agreed with the calibrated source activity.



Figure 9.
Inserting the underwater ISOCS detector into the ⁶⁰Co irradiation pool.

Release of "Contaminated" People in a Nuclear Power Plant with ISOCS

TVA's Sequoyah Nuclear Power Plant has purchased an ISOCS unit for various applications, including pipe scanning, waste assay, and evaluation of personnel contamination events. Entries into containment are frequently made at power or soon after shutdown. Everyone leaving containment must be checked for contamination; this is performed with total-body monitors. These are gross (non-spectroscopic) devices, and do not differentiate between internal or external nuclides, nor do they identify the nuclide.

Frequently they generate alarms, which must be investigated. If the source of the contamination cannot be found with a hand-frisking unit, then the worker must be taken to the Whole Body Counting system to check for internal contamination. This results in a loss of 2.5 hours of time. For entries during operation or shortly after shutdown, most of these contamination events are just $^{133}\text{Xe}/^{135}\text{Xe}$ gas adsorption or absorption, not particulate internal or external contamination.

Now, they place the ISOCS unit at the contamination control area, and if there is an alarm, then the person is assayed using ISOCS as a portable WBC system. Now, the procedure only takes five minutes.

Measurement of High Level Ion-exchange Resins at Nuclear Reactor for Reduced Waste Disposal Costs

The EPZ Nuclear Power Plant in Borssele Netherlands had accumulated contaminated ion-exchange resins over the past 10 years of operation. This was to be disposed as radioactive waste. Local restrictions place a maximum activity of 4E11 Bq (10 Ci) ^{60}Co and 2E12 Bq (50 Ci) ^{137}Cs per drum. Since the cost for disposal of each drum is very high, it was desired to place the maximum permissible activity in each container to minimize the number of containers.

Traditional methods of quantification include dose rate measurements and activity conversions, and/or sampling of a few mg for laboratory analysis. Neither of these methods are very accurate since the Co/Cs ratio is not uniform in the material. Instead, ISOCS was used to assay 10 kg batches of resin prior to loading into the disposal container. The measured batch was then added to the drum, as long as its activity did not make the total container exceed the limits. The measurements were performed by Michel Ceuppens of Canberra-Benelux.

Because of this assay technique, each drum could hold over 2.5 times as much resin than with the traditional measurement techniques. This resulted in a several million dollar waste disposal cost savings.

CONCLUSIONS

Various applications have been shown here that demonstrate the potential advantages to users of *in situ* gamma spectroscopy and the ISOCS system. Ge gamma spectroscopy is quite easy for typical users to interpret, and for the software to automatically analyze. Gamma spectroscopy tells the user exactly what radionuclides are present. The mathematical efficiency calibrations allow users to create complex calibrations in a few minutes without radioactive sources. And the extensive documentation provided in a Ge spectrum, which is stored with all analysis parameters the Canberra CAM file, provide much security that the user can defend these results years later if they are questioned.

ACKNOWLEDGMENTS

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Ron Thurlow and Matt Scannell, Seabrook Nuclear Power Plant.

Radoslav Radev, Ph.D., and David Hickman, Ph.D., Lawrence Livermore National Laboratory.

John Stewart, Ph.D., Sequoyah Nuclear Power Plant, TVA.

- 1 NUREG-1496, Generic Environmental Impact Statement in Support of Rulemaking on Radiological Criteria for Decommissioning of NRC-Licensed Nuclear Facilities, USNRC, Aug 1994.
- 2 *In Situ* Object Counting System (ISOCS), Innovative Technology Summary Report, Chicago Pile 5 (CP-5) Test Reactor Large Scale Demonstration Project, Argonne National Laboratory, Dec 1997.
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***In Situ* Gamma Spectroscopy for Assessment of Contaminants in Soil**

L. F. Booth, D. W. Groff and F. L. Bronson
Canberra Industries, Meriden, CT., USA
November, 1996

Introduction

In situ gamma spectroscopy offers an efficient and accurate method for characterizing large area or volume sources of dispersed radioactivity in the vicinity of nuclear facilities. These measurements can be useful in providing initial characterization information at a potentially contaminated site or in verifying the effectiveness of decontamination efforts. A particularly useful application is the *in situ* determination of contaminants in or on soil. The objective is to determine the activity of radionuclides per unit area or unit volume of soil. Traditional methods typically involve an initial scan with gross (nonspectroscopic) counting instruments, followed by extensive soil sampling and laboratory gamma spectroscopic analyses. These methods often require significant labor and long turn around times and provide information only about the discrete samples collected. *In situ* spectroscopy, on the other hand, can provide immediate results and will detect all the gamma radioactivity in the area viewed, thereby reducing the possibility of missing isolated deposits or hot spots.

For an *in situ* system to be suitable for field measurements, it should have the following characteristics: it must be portable, with a self contained power supply; it should have an easy to use, automated software package which enhances production type counting; and it must be calibrated for the source and matrix geometries encountered in the field. For soil counting, the system should be capable of quantifying the radionuclides viewed, performing accurate analyses for the various distributions of contaminants in soils,

including uniform and exponential vertical distributions and semiinfinite and restricted fields in the horizontal directions. A typical Canberra *in situ* system includes a Coaxial Ge detector in a Multi-Attitude Cryostat, an InSpector Portable Spectroscopy Workstation, heavy duty detector tripod and collimator, and a notebook computer with Genie-PC/PROcount software.

In August, 1995, the Canberra Special Services Group (SSG) participated in a project to evaluate and demonstrate field screening technologies which would facilitate waste minimization during excavation and disposal of contaminated soils at Formerly Utilized Sites Remedial Action Program (FUSRAP) sites. The purpose of the study was to demonstrate that *in situ* gamma spectroscopy technology is a valid, cost effective method for data collection during characterization, remedial action and verification activities. The study concluded that correlation of *in situ* results and soil sample laboratory results are generally very good for a wide range of geometries and contamination conditions(1). In addition, *in situ* technology was shown to be able to provide results quickly and is cost effective in most cases.

***In Situ* System**

The Canberra SSG *in situ* system consists of a 45% relative efficient Ge detector, Multi-Attitude Cryostat with a 3-day LN₂ holding time, a one inch thick lead shield/collimator, adjustable tripod stand, InSpector Workstation and notebook computer. The Genie-PC/PROcount software was loaded with approximately 40 separate efficiencies for various

source distributions in soil. Canberra personnel transported the system into the field, set up and acquired data at designated locations. Using the PROcount software, data are acquired, analyzed and stored automatically, minimizing user operations in the field.

System Calibration

To obtain valid results, the *in situ* gamma spectroscopy system must be accurately calibrated. Multiple efficiency calibrations will be required to resolve many possible distributions in soil, which include uniform distributions for naturally occurring radionuclides, exponential distributions for materials deposited on the surface or discrete layer distributions for layers of materials on or below the surface. Contaminants may extend to infinite distances horizontally, or may be limited to confined areas of elevated or "hot spot" deposits. Correct efficiency calibration factors must be applied to each distribution to obtain accurate measurements of concentrations or activity inventories in soils.

The Canberra detector calibration technique combines a reliable, proven mathematical calibration method with a source/detector measurement validation protocol to provide accurate calibrations for a variety of geometries. Mathematical calibrations are preformed with data generated with the Monte Carlo Neutron Photon (MCNP) model developed by Los Alamos National Laboratory. These calibrations are validated using actual detectors and calibration sources, then converted into various vertical distributions following techniques in EML-300(2). The MCNP calibrations have been shown to be accurate to within $\pm 10\%$, if the actual distribution is that which was modeled(3). The Canberra SSG system was provided with soil calibrations for four different heights above ground (1, 2, 3 and 10 meters above ground), for four vertical distributions at each of these heights (ranging from surface or fresh fallout deposition to uniform distribution) and for five horizontal distributions [infinite, 100 m², 25 m², 10 m² and 1 m² areas (uniform vertical distribution)].

Field Measurements

As part of a demonstration study sponsored by the Department of Energy, the *in situ* system was tested under a wide range of contamination conditions at a

FUSRAP site in New Jersey. This site is known to be contaminated with natural thorium from previous manufacturing processes. A set of *in situ* measurements were performed and the results compared to composite soil sample results to determine if the two methods produce comparable results and how *in situ* technology could be utilized for site characterization and verification surveys.

The DOE has established remedial action criteria for Th-232 and daughters at FUSRAP sites based on average concentrations in soil. The criteria for release are: 5 pCi/g (0.2 Bq/g) average concentration in the top 15 cm (6 in.), and 15 pCi/g (0.6 Bq/g) average concentration below 15 cm, with survey areas not to exceed 100 m². Levels in excess of 5 pCi/g will be allowed if they are isolated "hot spots" 25 m² or less and concentrations are $< (100/A)^{1/2} \times 5$ pCi/g, where A = area of hot spot.

The demonstration project required *in situ* detection of release criteria at reasonable count times and quantification of hot spots. A lead shield collimator was placed around the detector to "focus" the detector to view restricted fields of 100 m², 25 m², 10 m² and 1 m² areas. At each measurement location, soil samples (3 or 4 for areas >10 m², one for smaller areas) were collected and composited, then counted on a laboratory gamma spectroscopy system. At all locations, samples were collected at surface (0-15 cm) and subsurface (15-30 cm) depths to obtain an indication of vertical distributions, and then were combined to provide a final value for that location. All *in situ* measurements were performed at a height of one meter and all distributions were assumed to be uniform, although that condition was known not to be the case at some locations.

The mathematical calibrations assumed the lead collimator was effective in shielding all photons which originated from outside the field of view. This assumption is generally valid for photons with energies less than 1 MeV, but is not true for photons above that level. A fraction of high energy photons, such as the K-40 gamma at 1.46 MeV or the Tl-208 gamma at 2.61 MeV, will penetrate the collimator and cause an apparent over response for highly collimated geometries. *In situ* results have not been corrected for this effect.

Results

The Canberra *in situ* system demonstrated excellent sensitivity for naturally occurring radionuclides in soil. The detection limit for Th-232, when inferred from daughters, was less than 1 pCi/g for a 15 minute count for all fields of view. Table 1 shows typical detection limits for nuclides of interest, assuming no interferences from other sources. As the field of view decreases, the detection limits increase due to the reduction in sample size.

A comparison of *in situ* vs. soil sample results for uniform distributions is shown in Table 2. For areas of thorium deposits, uniformity was defined as locations where the laboratory analyses for surface (0-15 cm) concentrations and subsurface (15-30 cm) concentrations differed by less than a factor of two. Good correlation is observed in most cases, with the soil sample results biased higher than the *in situ* results, which may be explained by sample processing, as discussed later. The exception is for K-40 for restricted views, where penetration of the high energy (1.46 MeV) gamma through the collimator causes an *in situ* over response.

Tables 3a and 3b show results for nonuniform distributions. Surface distributions (Table 3a) are those where the surface sample concentration was at least twice the subsurface sample concentration, and subsurface distributions are the reverse. In both cases, the soil sample results exceed the *in situ* results. While this might be expected for subsurface deposits, it is not anticipated for surface distributions. For exponential distributions, the ratio of concentrations between *in situ* measurements, where a uniform distribution is assumed, and soil samples collected to a depth of 15 cm, should be greater than one; i.e. the *in situ* results should be larger than the soil sampling results(4). Deviation from this predicted response may be explained by the limited soil sampling, or by a nearly uniform distribution in the top 15 cm, especially for low energy photons.

Soil sample results shown in Tables 2 and 3 are as reported by the laboratory, and are for processed samples. A part of the apparent bias between *in situ* results and sample results can be explained by this, since *in situ* counts are performed on "unprocessed" or wet samples. To evaluate this variability, a set of 18 samples were analyzed in the lab both with and without normal processing, which consists of sieving, grinding and drying. Table 4 shows the differences in lab results vs. *in situ* results, for both "wet" and "dry" samples. The processing results in an increase of 15-30% in reported concentrations for soil samples. When wet soil sample results are compared to *in situ* results, excellent agreement is obtained for uniform distributions.

Conclusions

The results of this study show that *in situ* gamma spectroscopy can be used as an alternative to, or to supplement, soil sampling when performing site characterization or when supporting site remediation. *In situ* systems can be set up easily and quickly in the field, and provide immediate on-site results. In many situations, *in situ* technology is more cost effective than extensive soil sampling and laboratory analyses. *In situ* measurements also provide a better measure of total site inventory and are less likely to be adversely impacted by nonhomogeneity or hot spots.

Comparison of *in situ* results to soil sampling results must consider the true distributions of contaminants in soil and the impact of sample processing. Deviations between the two methods should be expected for all but the most ideal conditions, although the variances will be acceptable in most cases. The *in situ* technology has the advantage of averaging variations over a large sample, thus providing a more accurate estimate of activities and concentrations.

Table 1.
Typical MDA values for in situ soil measurements. Uniform vertical activity distribution,
900 s count, 45% rel. eff. detector, one meter above the surface. All values in pCi/g.

| Nuclide | Primary Energy Line Used (keV) | No Collimation | 100 m ² Coll | 10 m ² Coll | 1 m ² Coll |
|---------|---|----------------|-------------------------|------------------------|-----------------------|
| K-40 | 1462 | 0.3 | 0.3 | 0.4 | 2 |
| Cs-137 | 662 | 0.05 | 0.06 | 0.09 | 0.3 |
| Tl-208 | 583 | 0.02 | 0.02 | 0.02 | 0.1 |
| Pb-212 | 238 | 0.2 | 0.2 | 0.2 | 1 |
| Bi-214 | 609 | 0.1 | 0.1 | 0.2 | 0.4 |
| Pb-214 | 352 | 0.2 | 0.2 | 0.2 | 0.9 |
| Ac-228 | 908 | 0.2 | 0.2 | 0.2 | 0.9 |
| Pa-234m | 1001 | 5 | 5 | 8 | 30 |
| Th-234 | 63 | 6 | 6 | 7 | 30 |
| U-235 | 186 | 0.2 | 0.2 | 0.2 | 0.4 |
| Th-232 | (Based on the Tl-208 peak at 2614 keV) | 0.05 | 0.05 | 0.06 | 0.3 |

Table 2.
In situ vs. soil sampling results for uniform distributions. Soil samples are dried, composited and averaged over surface and subsurface. Those distributions marked Bkg are from locations of natural background, while those marked All include both background and thorium deposits determined to be uniform from soil sampling. All results are in terms of pCi/g. Errors are counting uncertainties at 95% C.L.

| | | | | |
|---|-------------|----------------|--------------------|----------------|
| View = A (uncollimated) Distribution = Uniform (Bkg) Measurements = 6 | | | | |
| | Lab (Dry) | <i>In Situ</i> | | |
| K-40 | 10.36 ±0.82 | 7.97 ±0.46 | | |
| Ra-226 | 0.56 ±0.07 | 0.55 ±0.07 | | |
| Th-232 | 0.81 ±0.09 | 0.58 ±0.12 | | |
| View = B (100 m2) Distribution = Uniform (Bkg) Measurements = 3 | | | | |
| | | | Uniform (All) 7 | |
| | Lab (Dry) | <i>In Situ</i> | Lab | <i>In Situ</i> |
| K-40 | 11.03 ±0.90 | 8.67 ±0.50 | 10.84 ±0.88 | 7.76 ±0.53 |
| Ra-226 | 0.74 ±0.07 | 0.51 ±0.09 | 0.67 ±0.07 | 0.56 ±0.11 |
| Th-232 | 1.07 ±0.10 | 0.64 ±0.12 | 1.70 ±0.11 | 1.55 ±0.17 |
| View = D (10 m2) Distribution = Uniform (Bkg) Measurements = 1 | | | | |
| | | | Uniform (All) 3 | |
| | Lab (Dry) | <i>In Situ</i> | Lab | <i>In Situ</i> |
| K-40 | 9.59 ±0.81 | 8.67 ±0.69 | 8.96 ±0.84 | 8.07 ±0.55 |
| Ra-226 | 0.52 ±0.06 | 0.31 ±0.09 | 0.88 ±0.05 | 0.60 ±0.17 |
| Th-232 | 0.75 ±0.15 | 0.40 ±0.10 | 4.53 ±0.26 | 3.48 ±0.25 |
| View = E (1 m2) Distribution = Uniform (Bkg) Measurements = 2 | | | | |
| | | | Uniform (All) 4 | |
| | Lab (Dry) | <i>In Situ</i> | Lab | <i>In Situ</i> |
| K-40 | 10.87 ±0.88 | 15.70 ±1.95 | 10.40 ±0.92 | 16.65 ±2.28 |
| Ra-226 | 0.53 ±0.07 | 0.60 ±0.25 | 0.70 ±0.07 | 0.72 ±0.25 |
| Th-232 | 0.85 ±0.10 | 0.96 ±0.35 | 2.69 ±0.18 | 2.90 ±0.52 |

Table 3b.

In situ measurements vs. soil sampling for subsurface distributions. Subsurface distributions were defined by soil sampling. Any location where concentrations for the second 6 inch (15 cm) sample were twice the top 6 inch sample were termed subsurface, or deep, distributions. Soil sample results are the average of the surface and subsurface samples and *in situ* results are for uniform distributions. All results are pCi/g. Errors are counting uncertainties at the 95% C.L.

| View = C (25 m ²) Distribution = Subsurface Measurements = 1 | | | View = D (10 m ²) Distribution = Subsurface Measurements = 3 | | |
|--|-------------|----------------|--|-------------|----------------|
| | Lab | <i>In situ</i> | | Lab | <i>In situ</i> |
| K-40 | 15.86 ±1.20 | 10.60 ±1.60 | K-40 | 12.32 ±0.96 | 10.79 ±1.40 |
| Ra-226 | 1.30 ±0.11 | 0.78 ±0.21 | Ra-226 | 1.36 ±0.10 | 0.85 ±0.19 |
| Th-232 | 13.31 ±0.47 | 6.55 ±0.66 | Th-232 | 10.58 ±0.35 | 5.67 ±0.46 |

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Table 3a.

In situ measurements vs. soil sampling for surface distributions. Surface distributions are determined by soil sampling results. Any location where the concentrations in the top 6 inch (15 cm) sample were twice those in the second 6 inch sample were defined as surface distribution by SAIC. Soil sample results are the average of the surface and subsurface samples and *in situ* results are for uniform distributions. All results are pCi/g. Errors are counting uncertainties at 95% C.L.

| | | | | | |
|---|-------------|----------------|---|-------------|----------------|
| View = A (Uncollimated) Distribution = Surface Measurements = 3 | | | View = D (10 m ²) Distribution = Surface Measurements = 4 | | |
| | Lab (Dry) | <i>In situ</i> | | Lab (Dry) | <i>In situ</i> |
| K-40 | 8.61 ±0.75 | 5.13 ±0.61 | K-40 | 9.89 ±0.83 | 8.62 ±0.92 |
| Ra-226 | 2.00 ±0.08 | 0.97 ±0.07 | Ra-226 | 2.15 ±0.16 | 1.36 ±0.66 |
| Th-232 | 8.52 ±0.33 | 5.39 ±0.32 | Th-232 | 16.67 ±0.55 | 14.22 ±0.75 |
| View = B (m ²) Distribution = Surface Measurements = 8 | | | View = E (1m ²) Distribution = Surface Measurements = 2 | | |
| | Lab (Dry) | <i>In situ</i> | | Lab (Dry) | <i>In situ</i> |
| K-40 | 9.76 ±0.86 | 6.16 ±0.81 | K-40 | 9.30 ±6.80 | 15.20 ±2.20 |
| Ra-226 | 1.83 ±0.12 | 1.08 ±0.23 | Ra-226 | 1.29 ±0.10 | 1.26 ±0.54 |
| Th-232 | 9.53 ±0.37 | 8.71 ±0.62 | Th-232 | 6.67 ±0.36 | 11.12 ±1.10 |
| View = C (25 m ²) Distribution = Surface Measurements = 4 | | | | | |
| | Lab (Dry) | <i>In situ</i> | | | |
| K-40 | 10.35 ±0.87 | 7.68 ±1.11 | | | |
| Ra-226 | 2.56 ±0.15 | 1.55 ±0.48 | | | |
| Th-232 | 19.19 ±0.63 | 14.62 ±0.87 | | | |

Table 4.

In situ vs. lab results for wet and dry sample processing.
Wet samples are taken directly from the field and counted.
Dry samples are oven dried, sieved and ground. All results in
pCi/g. Errors are counting uncertainties at the 95% C.L.

View = All views
Distribution = Uniform
Measurements = 18

| | Lab Results | | <i>In situ</i> |
|--------|------------------|-----------------|-----------------|
| | <u>Dry</u> | <u>Wet</u> | |
| K-40 | 10.33 \pm 0.84 | 8.36 \pm 0.80 | 8.40 \pm 0.90 |
| Ra-226 | 1.06 \pm 0.07 | 0.79 \pm 0.07 | 0.72 \pm 0.15 |
| Th-232 | 4.26 \pm 0.16 | 3.42 \pm 0.22 | 3.70 \pm 0.23 |

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USE OF A CUSTOMIZED GAMMA SPECTROSCOPY SYSTEM FOR CHARACTERIZATION OF PROCESSED SOIL AT THE KERR-MCGEE SITE IN WEST CHICAGO, ILLINOIS

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ABSTRACT

During remediation activities at the Kerr-McGee (K-M) site in West Chicago, Illinois, contaminated soil is excavated and processed to produce separate output streams with different particle sizes. Most of the radioactive contamination is retained in the output material with the smaller particles, which is segregated for off-site disposal. The output stream with the largest particles is continuously monitored with a gamma spectroscopy system to quantify the residual nuclide activity levels. This system includes two large-volume germanium detectors, a DEC AXP computer, and a customized software package developed by Canberra Industries. A complete acquisition and analysis cycle is repeated at 30-second intervals, providing MDA values below the applicable release limits for ^{232}Th , ^{238}U and ^{226}Ra . Material with activity levels below these limits is stored for use as backfill in previously excavated areas on K-M property. Approximately 43,000 tons (34,000 cubic yards) of backfill material was released in 1998, with a significant cost savings compared to off-site disposal of all excavated material.

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INTRODUCTION

As part of the ongoing remediation activities at the Kerr-McGee (K-M) site in West Chicago, Illinois, large volumes of contaminated soil must be excavated and replaced with acceptable backfill material. To satisfy this need for backfill material and to reduce off-site disposal costs, K-M has developed a method for processing the excavated soil.

On-site processing operations separate the original input material into three output streams, each with a different range of particle sizes. During this process, most of the radioactive contamination is retained in the material with the smaller particle sizes, which is shipped off-site via rail car for disposal. The output stream with the largest particle sizes is continuously monitored with a customized gamma spectroscopy system to quantify residual activity levels.

Measured ^{232}Th , ^{238}U and ^{226}Ra activity results are used to divert the monitored material into two final output streams. Material with results exceeding the applicable release limits is reprocessed for further activity reduction. Material meeting the release criteria is stored for use as backfill in excavated areas.

INITIAL PROCESSING

Excavated soil is taken from a stockpile and loaded into the primary feed hopper at an average rate of approximately 100 tons/hour (Figure 1).

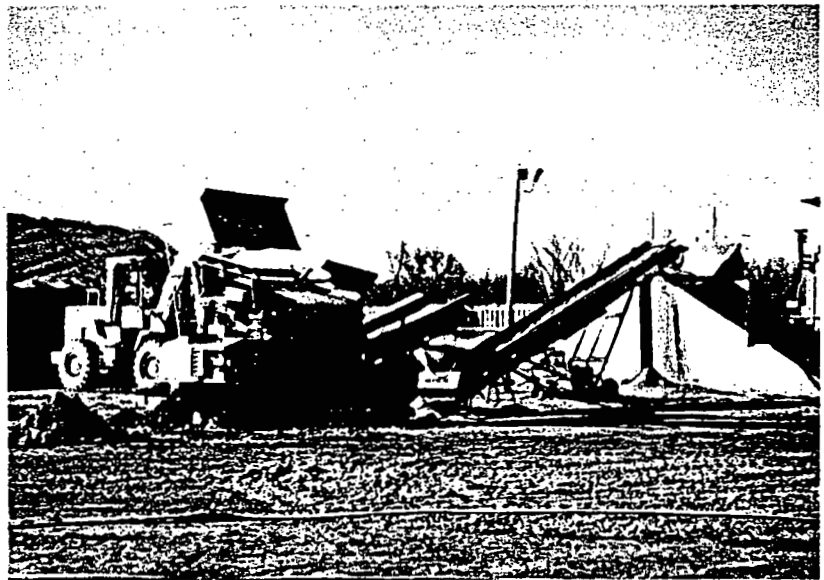


Figure 1.
Primary Feed Hopper

The soil is moved on conveyor belts through a series of water sprayers, tumblers and screens, to segregate material with the largest particle sizes (Figure 2).

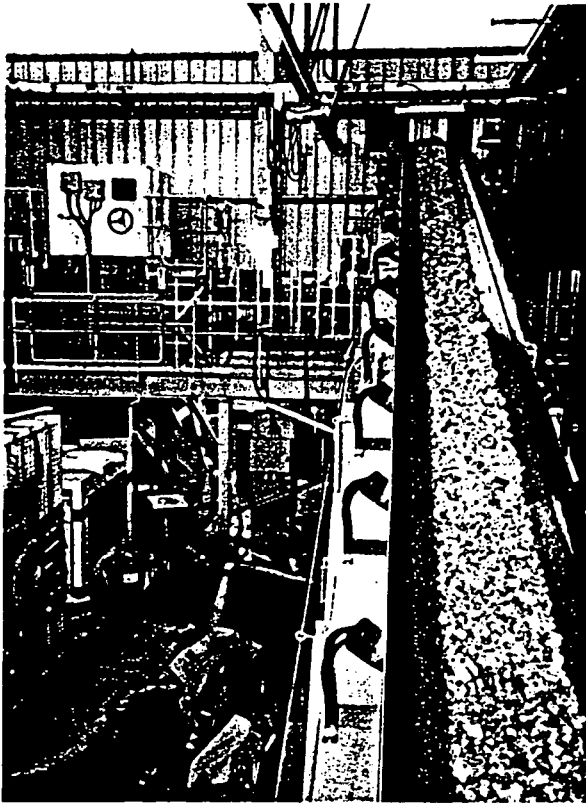


Figure 2.
Material with Largest Particle Sizes

This material is deposited onto a special Activity Characterization Conveyor (ACC) belt for analysis (Figure 3).

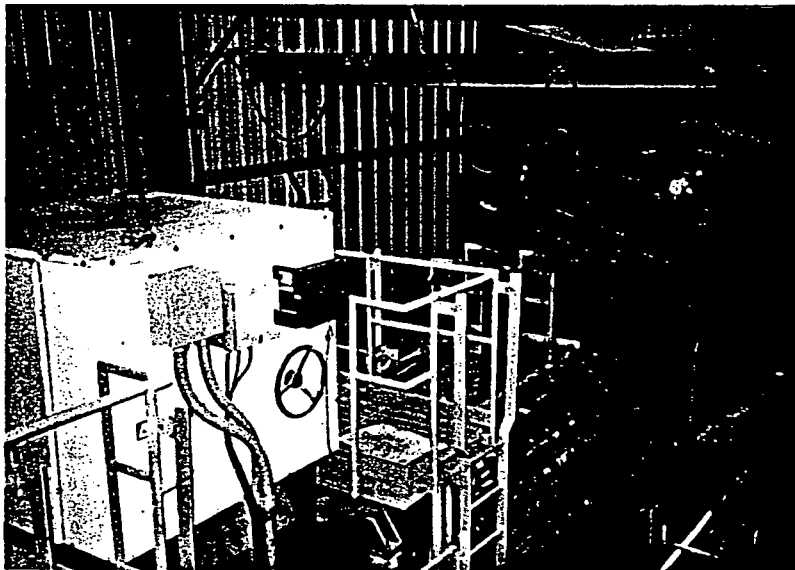


Figure 3.
Activity Characterization Conveyor

MEASUREMENT METHOD

A customized gamma spectroscopy system is used for continuous monitoring of material on the ACC belt. This system includes two collimated HPGe detectors mounted directly above the ACC, inside a climate-controlled enclosure (the white box shown in Figure 3).

The system is controlled by a DEC AXP computer and a special software package developed by Canberra Industries. This system also includes a separate PC and monitor for graphical displays of material output vs. time, a printer, and a backup tape drive (Figure 4).



Figure 4.
Customized Gamma Spectroscopy System

Material is transported beneath the detectors at speeds ranging from 3 – 12 feet/minute. To compensate for varying feed rates, height sensors automatically adjust the ACC belt speed to maintain a constant 8" height of material on the belt (Figure 5).

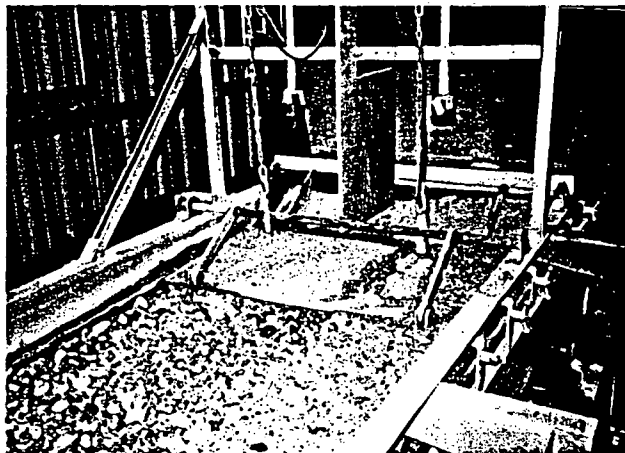


Figure 5.
Height Sensors for Conveyor Speed Control

The effective sample size viewed by the detectors is an 8" thick rectangular slab, approximately 10 cubic feet in volume. Side rails above the ACC belt maintain a constant 44" width of material, providing a fixed counting geometry and allowing a single efficiency calibration function to be used for all analyses (Figure 6).

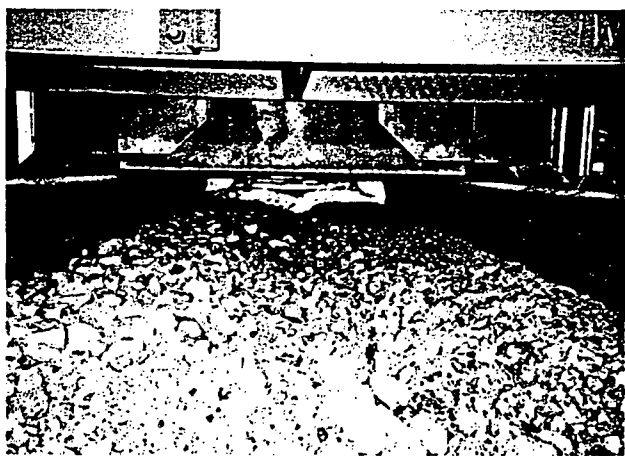


Figure 6.
Fixed Sample Material Counting Geometry

A complete acquisition and analysis cycle is repeated at 30-second intervals, which is adequate to achieve the following MDA values:

^{226}Ra (^{214}Bi): 0.4 pCi/g

^{232}Th (^{228}Ac): 0.4 pCi/g

^{238}U ($^{234\text{m}}\text{Pa}$): 5 pCi/g

Spectra from consecutive counts are summed on a channel by channel basis, then reanalyzed to determine "long-term average" activity values. Updated long-term average values are recalculated following each 30-second cycle, after summing all spectra acquired in the last 20-minute time period.

Long-term average activity results are compared to material release limits established for the K-M site. These release limits are as follows:

Total Radium - 7.2 pCi/g (5.0 + 2.2 Bkg)
[^{226}Ra + ^{228}Ra]

Total Uranium - 10 pCi/g plus credit factor
[$2.046 \times ^{238}\text{U}$] (credit factor = 2 to 8 pCi/g,
maximum of 8 allowed if
Total Radium < 5.0 pCi/g)

FINAL PROCESSING

Measurement results are used to control a diverter gate, which divides all monitored material leaving the ACC into one of two final output streams (Figure 7).



Figure 7.
Diverter Gate for Backfill/Recycle Decision

The proper diverter gate position is re-determined after each 30-second acquisition/analysis cycle, with a time delay to allow the "sample" of material corresponding to each cycle to reach the gate. Material with long-term average activity results exceeding the release limits is diverted to a "recycle pile" inside the controlled area, then saved for subsequent reprocessing (Figure 8).

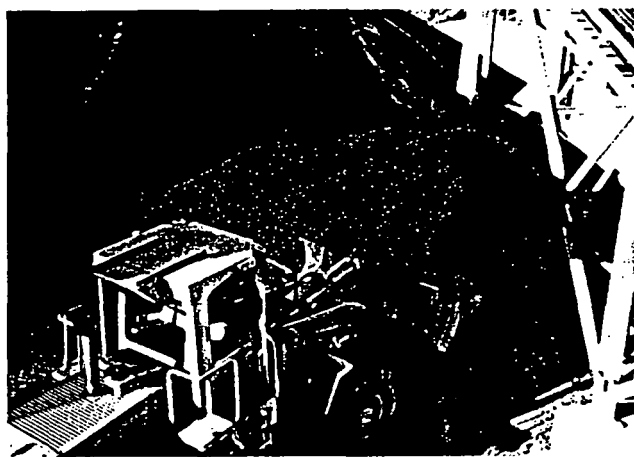


Figure 8.
Recycled Material is Saved for Reprocessing

Material satisfying all release limits is routed to a final conveyor chute and deposited outside the controlled area. The exit point of this conveyor can be moved to allow accumulation of multiple "backfill piles", pending transport of this material to previously excavated areas on K-M property (Figure 9).



Figure 9.-
Multiple Piles of Releasable Backfill Material

After placement and compaction of backfill material in remediated areas, *in situ* gamma spectroscopy measurements are performed at selected survey locations for final verification purposes. The system used for these *in situ* measurements includes a portable MCA, laptop PC, and collimated HPGe detector mounted on a trailer. A utility vehicle is used to pull the trailer and provide 12 V battery power for all equipment (Figure 10).

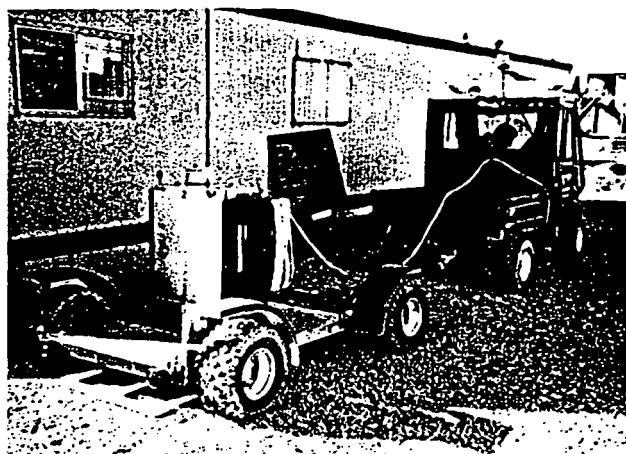


Figure 10.
In Situ Measurement System

Results from these final *in situ* measurements have been consistent with the original results from continuous monitoring of processed material on the ACC belt. Additional comparative measurements based on traditional laboratory sample analyses have confirmed that the original results used to release the backfill material are accurate and reliable.

CONCLUSION

Processing of contaminated soil was performed at the K-M site from April to December in 1998, and will resume in early 1999. Typical output of releasable backfill material during normal operating conditions was approximately 400 tons/day (about 50% of the original soil input). Final verification surveys using *in situ* measurement techniques have confirmed that this backfill material satisfies the applicable release limits. Approximately 43,000 tons (34,000 cubic yards) of backfill material was released in 1998, resulting in a significant cost savings compared to off-site disposal of all excavated material.

ACKNOWLEDGMENTS

- 1) The complete system used for material processing operations at the Kerr-McGee site is named the Simplified Physical Separation Facility (SPSF). Initial engineering and software development support for the SPSF was provided by Lockheed/Martin. Subsequent engineering and electrical designs, software for material flow control, and SPSF hardware installation was provided by M3 Engineering.
- 2) The feasibility of using the SPSF for processing and monitoring contaminated soil was initially confirmed through pilot testing with prototype systems designed and constructed by Kerr-McGee. (Various patent applications are on file.)
- 3) The system used to perform *in situ* measurements for final verification of released backfill material is named the Field Verification System (FVS). The FVS was designed by Lockheed/Martin and Kerr-McGee, and uses standard Canberra hardware and software (Genie-2000) for gamma spectroscopy measurements.
- 4) Many thanks to Dr. Gareth Van De Steeg and Mr. Mark Krippel at Kerr-McGee for supporting the presentation of this paper at the 32nd Midyear Topical Meeting of the Health Physics Society, January 24-27, 1999, Albuquerque, New Mexico.

USE OF *IN SITU* GAMMA SPECTROSCOPY TO SUPPORT DECONTAMINATION AND DECOMMISSIONING ACTIVITIES

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ABSTRACT

In Situ gamma spectroscopy is a valuable tool for supporting decontamination and decommissioning (D&D) activities at nuclear facilities. These measurements save money and time in the characterization, decontamination and release of buildings and grounds, when compared to the conventional process of extracting samples and sending them to a remote laboratory for analysis. The Canberra *In Situ* Object Counting System (ISOCS) is a portable gamma spectroscopy system that has been deployed at several sites performing D&D work, with successful results. This paper describes these applications and identifies specific advantages over more conventional methods.

The 903 Pad Project at the Rocky Flats Environmental Technology Site (RFETS) involves the assessment of the extent of surface and subsurface soil contamination resulting from past accidental releases of Pu and U. *In situ* gamma spectroscopy was selected as the preferred method for evaluating the areal surface contamination because of the method's ability to directly measure large surface areas in short count times and to obtain immediate results. Target nuclides for *in situ* measurements were Am-241, U-235 and U-238, with Pu derived from Am-241. Because of the low energy photon emissions from Am-241 and U isotopes, careful modeling of the soil contamination, which addressed vertical distributions, soil chemical

composition and moisture content, was critical. Over 1000 measurements were completed, with results providing distributions as expected and showing excellent agreement with soil sampling.

An ISOCS system was deployed in a mobile on-site laboratory to provide analysis of samples collected from the area designated as Trench One at the RFETS. Rapid feedback was required to help guide the trench excavation and to decide the proper disposition of the excavated materials. Since the nature of the samples collected from the trench could not be accurately predicted, it was not practical to purchase and/or prepare actual counting standards with the same matrices. This problem was resolved by ISOCS' ability to mathematically model the samples, and to adjust those models as needed, to derive valid efficiency calibrations on a sample-by-sample basis. This system was particularly useful in modeling the sample source/matrix configuration of unknown masses of depleted U possibly contaminated with low levels of Am-241, since disposition of the depleted U depended upon the level of Am present.

The Barnwell Nuclear Fuel Plant in South Carolina was constructed to reprocess spent fuel but was never put into commercial operation. However, initial system testing was performed using solutions containing low levels of U, Pu and Am-241. Decommissioning of these facilities requires characterization of systems, which has been performed using ISOCS as one of the key

tools. Modeling and *in situ* counting of complex components such as tanks, traps, glove boxes, filter banks and piping eliminates the need to open and/or dismantle systems for characterization purposes. Estimates of levels of internal contamination obtained with ISOCS measurements have been consistent with other methods where comparisons are available.

I. INTRODUCTION

In situ gamma spectroscopy has been used to support characterization, decontamination and decommissioning activities at commercial and government sites. The ISOCS instrument now makes this quick, accurate, and easy to do. This instrument has the ability to make sensitive measurements in the field and to provide immediate laboratory-quality results. It has been shown to provide results comparable to other measurement methods and has been found to be economically advantageous for a number of applications.

ISOCS consists of a Ge detector (many different types and sizes are available), mounted in a multi-attitude cryostat which allows the detector to be pointed in any direction, connected to a battery operated InSpector MCA and laptop PC, an ISOCS shield and cart, and the ISOCS mathematical efficiency calibration software. The calibration software allows the user to model the object to be counted starting from a basic geometry templates, entering the construction and dimensions of the sample and the distance from the detector, and then executing the program which computes the energy-efficiency response. No radioactive sources are used, and the results are available in a few minutes. For each of the projects described below, the user(s) generated unique efficiencies for counting sample/geometry configurations which would otherwise have been difficult or expensive to create with conventional methods using radioactive sources.

I. SOIL MEASUREMENT APPLICATIONS

At the Rocky Flats Environmental Technology Site (RFETS), the 903 Pad Project required rapid and cost-effective assessment of the radioactivity in soil. The goal of this project was to provide detailed information regarding the extent of soil contamination on and in the vicinity of, the 903 Pad site, so that remedial action options can be evaluated, developed and implemented. A sampling plan, developed by RFETS and reviewed and approved by oversight and regulatory groups, formed the basis of the project scope of work. The plan specified that *in situ* gamma spectroscopy be used to characterize the study area of approximately 25 acres. A triangular grid pattern 10 meters on a side was used with measurement points at the grid intersections. Measurements were performed with a detector height of one meter with the detector collimated to restrict the field of view to approximately 10 meters. This measurement pattern provided 78% coverage of the study site.

The sampling plan identified the nuclides of interest, which included Am-241, U-235 and U-238, with required detection limits of 1, 0.5 and 5 pCi/g, respectively. Pu was derived from Am-241 using a previously established ratio for Pu-239/240 to Am-241 of 7:1. The vertical distribution of contaminants in the surface soils had been established in prior studies which showed that approximately 80% of the Pu and U contamination was contained in the top 5 cm (2 inches) of soils, with highest concentrations near the surface and levels decreasing rapidly with depth. These studies also provided data on the density, chemical composition, and moisture content of RFETS soils.

The ISOCS calibration software was used to calculate an efficiency appropriate for this application. The template used was the circular plane, with a diameter of 10 meters [larger

doesn't change the calibration], a vertical distribution containing 66% of the activity in the top 3 cm and 33% of the activity in the next 2 cm, a detector height of one meter and the typical RFETS soil composition which contains small amounts of Fe, Al and Mg at a density [for RFETS soils] of 1.3 g/cc. Alternative calibration models, with different horizontal and vertical distributions and soil compositions were tested to determine an approximate range of uncertainties in measured activity from inaccuracies in the calibration, and submitted to the user with the final report.

When using the normal efficiency as described above, a count time of about 20 minutes was needed to meet the required detection limits. The field measurement locations were documented with a commercial global positioning system (GPS). Field measurements commenced in September, 1998, and continued through February, 1999. Most of the study site was posted as a Radiological Controlled Area (RCA) and required protective clothing for the operators, and appropriate protection from contamination for the equipment. The *in situ* electronics were kept and operated in an all terrain vehicle when inside RCA (see Fig. 1 which shows the operator, the PC, and the InSpector MCA under the PC). The ISOCS detector, shield cart, and GPS are shown in Fig. 2; note that for this picture they are outside the RCA and the protective covering is removed for clarity.

Canberra provided a complete measurement service, which included *in situ* equipment and operators, health and safety coverage, soil sampling and packaging, grid layout and GPS measurements and electronic data reporting. Over 1100 sample measurements and 200 QC measurements (duplicates, controls and backgrounds) were completed and reported, allowing RFETS to meet performance goals. The ability to obtain immediate results was critical in



Figure 1 Operator in vehicle with ISOCS electronics

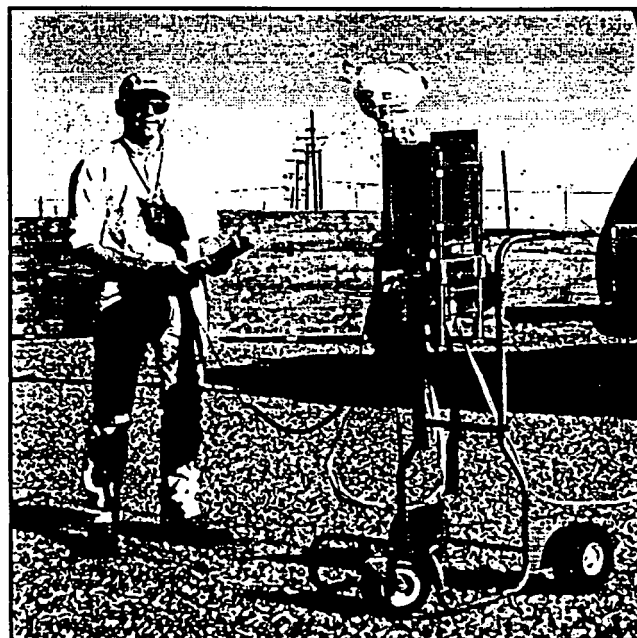
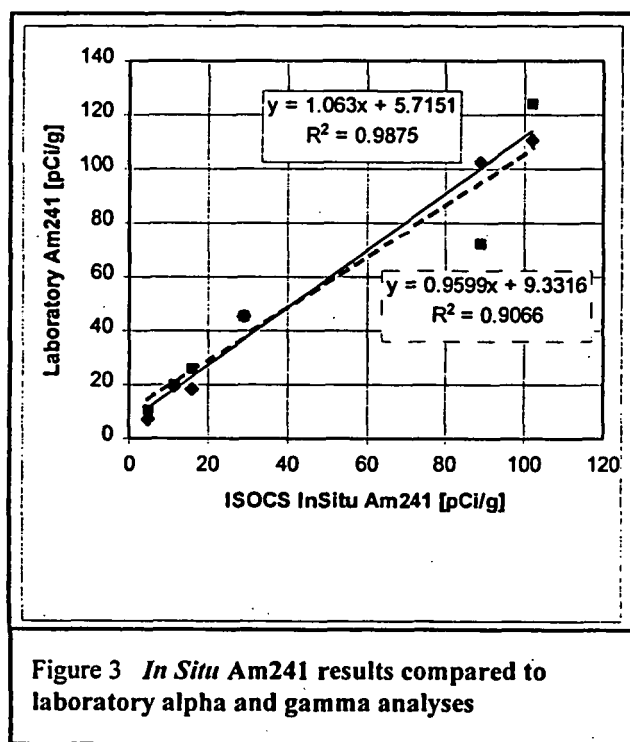


Figure 2 ISOCS *In Situ* System, collimated for measurement of soil contamination; with GPS

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bounding and limiting the scope of the study to those areas which exceeded the site action levels.

To provide independent validation of the mathematical calibrations, soil samples were collected from six grid locations chosen to cover a wide range of activities. These were analyzed at a commercial laboratory using both gamma spectroscopy and alpha spectroscopy. The ISOCS concentration when compared to the conventional soil sampling and laboratory analyses had excellent agreement as shown in Fig 3.



The *in situ* measurements were also less expensive and yielded the results in a more timely manner. For a complete *in situ* service, as described above, the estimated total cost for each grid measurement was \$300. For a comparable soil sampling program (multiple samples from each grid, composited, analyzed in the lab), the estimated cost is \$650, more than twice the cost of *in situ*. (This cost could have been reduced to

\$420 per grid if time were of no consideration, still 30% more than *in situ*).

III. FIELD LABORATORY APPLICATION

Trench-1 (T-1) was a successful D&D project that took place at the Rocky Flats Environmental Technology Site (RFETS) during the summer of 1998. Based on historical records and interviews with past and present employees, T-1 was used between 1954 and 1962 to dispose of drums containing depleted uranium turnings and chips from machining operations. The majority of the material was suspected to be depleted uranium; however the presence of enriched uranium and or depleted uranium contaminated with americium (thus plutonium) could not be discounted. In addition the trench was expected to contain other miscellaneous debris such as scrap metal, glass, graphite, plastics, wood and cemented cyanides. The actual number of drums and the total amount of the material were unknown at the beginning of the project. Fig. 4 shows the inside of the protective tent structure that was constructed over the trench which defined the RCA. The excavator is removing a drum from the trench in preparation for sampling it.

The contents of the trench were to be excavated, segregated by material and activity, and processed for shipment to an off site disposal facility. Canberra was required to establish a mobile gamma spectroscopy laboratory at the T-1 site and to quantify Am-241, U-235 and U-238 in depleted uranium in waste residue, soil, debris, and water samples collected from the drums and trench materials. The total Pu content was calculated from Am-241 activity using the an assumed age of the weapons grade plutonium. The degree of enrichment was determined based on the U-235/U-238 isotopic ratios. Results of these field laboratory sample assays were used to determine



Figure 4 Excavator removing drum from Trench-1

if the waste could be classified as low level waste (LLW) vs. transuranic (TRU) waste and to direct handling and disposal operations.

The mobile laboratory was configured with four gamma assay systems, two of which were ISOCS *in situ* systems with the detector in a conventional laboratory shield, as shown in Fig. 5. The 2 ISOCS system were used to assay 170 of the 235 samples submitted to the lab. The ability of ISOCS to quickly and accurately generate unique efficiencies for each different sample matrix and density and volume was critical to the project. Most of the samples contained uranium residues, contaminated with Am-241 and Pu. Since the content of U in the samples impacted the Am-241 assay by severe matrix absorption, it was necessary to establish the correct content of U in each sample. Guided by the physical characteristics of each sample, the ISOCS calibration software was used to derive the correct matrix model by adjusting the Uranium content (% of mass), the chemical characteristics (e.g. UO₂, U₃O₈, etc.) and sample density. The correct model was defined as that combination of parameters which produced approximately equal activities from the U-238 daughters Th-234 (derived from low energy

photons) and Pa-234 (derived from a high energy photon). The efficiency from that model was used to determine Am-241 in the sample. For maximum accuracy, each of the 170 samples assayed had a unique efficiency calibration.

The ISOCS modeling method was verified by counting a blind Performance Evaluation sample containing depleted U and Am-241 in activities unknown to Canberra. Those results were favorable, even though the Uranium in the PE sample had settled into a non-uniform distribution before the resin hardened. In addition, split samples were analyzed off-site by oversight agencies, with excellent

agreement. Use of the ISOCS systems provided a rapid, cost effective method of sample analysis in support of this D&D project and allowed the customer to meet a very demanding schedule which resulted in achieving a successful Performance Measure.

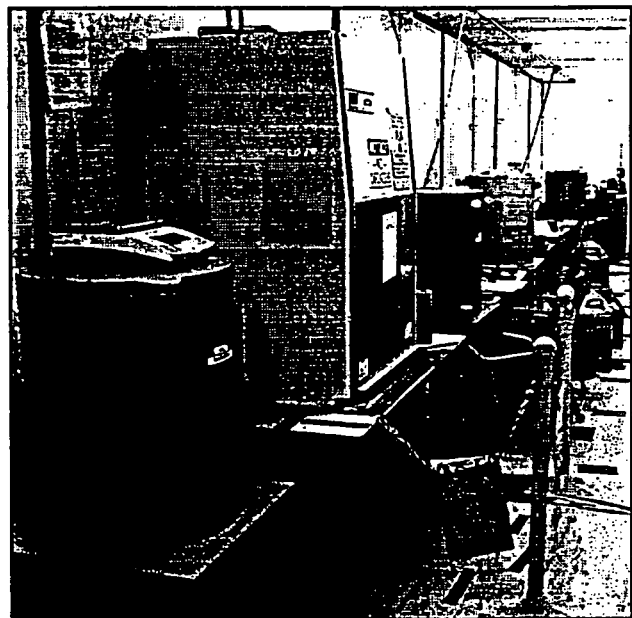


Figure 5 Field laboratory gamma spectroscopy systems and sample preparation hood

IV. ASSESSMENT OF CONTAMINATION ON OR IN LARGE OBJECTS.

In situ gamma spectroscopy can be used to assess the radioactivity content on the outside or inside of large stationary objects, eliminating the expense and potential hazards associated with opening or dismantling these components for traditional sampling purposes. Until recently, *in situ* measurements of such objects were often limited to nuclide identification only, due to difficulties in performing sample-specific efficiency calibrations. The cost and effort required to prepare, maintain and eventually dispose of traditional calibration sources is often prohibitive for large sample geometries. The ISOCS mathematical calibration software eliminates the need for these radioactive sources. ISOCS therefore provides a practical alternative method for accurate quantification of nuclide activity detected in these larger objects.

Decommissioning efforts have been in progress at the AGNS Barnwell Nuclear Fuel Plant (BNFP) in South Carolina during the past several years. These efforts have required radiological characterization of numerous tanks, pipes, glove boxes, fume hoods, and filters. The ISOCS calibration software allows proper modeling and efficiency determinations for these types of large objects. Canberra was contracted to provide ISOCS measurement services at BNFP, including equipment rental, operational personnel, and data reporting. ISOCS measurements were performed to characterize approximately 50 large objects during four separate site visits between January 1998 and February 1999. The results of these measurements were very helpful in guiding decommissioning activities.

BNFP site personnel were responsible for selecting the objects to be characterized, and for specifying nominal detection limits for each measurement. Due to the limited accessibility of

many of the measurement locations, BNFP personnel also assisted the Canberra operator with transport and setup of the ISOCS equipment. ISOCS measurements were performed for: (a) objects known to be contaminated based on recent gross-count survey measurements, (b) objects with suspected contamination based on available records of previous site processes, and (c) objects assumed to be free of contamination based on available records. Spectral acquisition times were frequently set to 60,000 seconds or longer (unattended overnight counting) to ensure adequate detection limits for objects of type (b) and (c) above.

For each ISOCS measurement, the standard 50 mm thick shielding components were used to surround the back and sides of the detector endcap to ensure that the detector was only seeing the desired object, not the many other radioactive items in the area. An additional 90-degree collimator cap was sometimes also used to further restrict the detector field of view when interfering sources were nearby. The distance between the detector endcap face and a suitable reference point on the outer surface of each object was carefully measured. Critical height, width, depth, diameter and wall thickness dimensions of each object were measured or obtained from available facility drawings. Target nuclides and other specific ISOCS modeling assumptions used at BNFP are summarized in the following sections.

A. Cylindrical Tanks

Approximately 20 cylindrical tanks were characterized, with outer diameter values ranging from 2 - 8 ft and height values (within the detector field of view) up to 8 ft. All tanks had stainless steel walls with thickness values <0.4 in. Internal contamination was assumed distributed in a thin layer on the inner wall surfaces, or uniform throughout various internal

components within the tank volume. The primary potential contaminant for each measured tank was natural uranium, with an expected Pa-234m/U-235 activity ratio of approximately 22/1. The "Simple Cylinder" template was normally used to input sample parameter values for ISOCS efficiency calibrations. Alternatively, for horizontal tanks with activity assumed distributed on the inner bottom surface, the "Pipe" template can be used to input sample data (see Fig. 6 for a typical horizontal tank). The reported Pa-234m activity values were consistent with previous expectations.

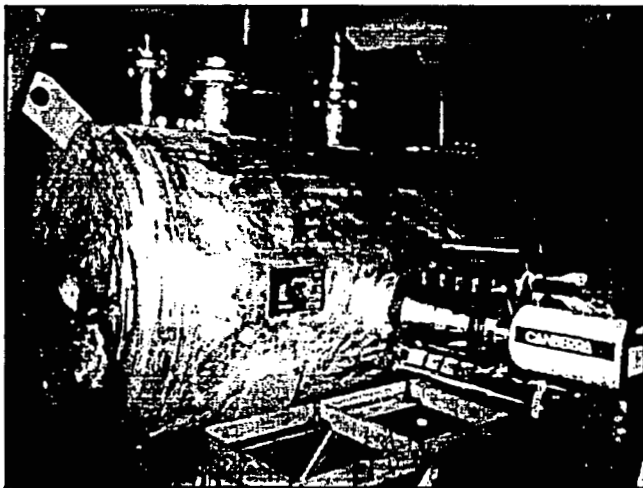


Figure 6 Horizontal tank during measurements with ISOCS

B. Glove Boxes and Fume Hoods

Approximately 15 measurements of sealed glove boxes and fume hoods were performed, generally with the detector viewing the inner bottom and rear wall surfaces through a vertical front wall of Plexiglas or leaded glass material (see Fig. 7 for typical example). Internal contamination was assumed distributed in a thin layer on the inner bottom or rear wall surface only. Any small items present on the bottom surface were ignored. The primary potential contaminants for these objects were Pu and Am-241, with a known Pu/Am activity ratio. The



Figure 7 Glove box undergoing ISOCS measurements

"Simple Box" and/or "Rectangular Plane" template was used to input sample parameter values for ISOCS efficiency calibrations. Reported Am-241 activity values were consistent with previous gross-count survey results.

C. Pipes and Drain Traps

Approximately 10 measurements of cylindrical pipes and "U-shaped" drain traps were performed, with outer diameter values ranging from 1.5 – 8 in. All of these objects had stainless steel walls with thickness values <0.4 in. Internal contamination was assumed distributed in a thin layer on the inner wall surfaces for straight pipes, or uniform throughout a volume of water filling each "U-shaped" drain trap. The primary potential contaminants for these objects were natural uranium (with an expected Pa-234m/U-235 activity ratio of approximately

22/1), or Pu and Am-241 (with a known Pu/Am activity ratio). The "Pipe" template was used to input sample parameter values for ISOCS efficiency calibrations for each of these objects. Reported activity values were consistent with previous expectations.

V. CONCLUSIONS

The Canberra ISOCS instrument has been shown to be an effective characterization tool to assist in all phases of remedial action projects. The mathematical calibrations allowed the generation of results which were shown to be in good agreement with conventional assessments. In these examples ISOCS was used to provide nuclide-specific activity quickly and economically for initial site characterization. And, it was used to provide rapid turnaround of activity results as feedback to the decommissioning crew to support the operational phases of a DD/ER project. And, for the one project that was finished, ISOCS was the major tool to prove that the area was suitable for project termination.

ISOCS, AN IN-SITU SYSTEM AND PORTABLE GAMMA SPECTROSCOPY LAB THAT CAN BE TAKEN TO THE ACCIDENT SITE

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SUMMARY

Under most emergency situations, external dose-rates are fairly easy to measure, but determining the specific nuclides and their concentrations, has been much more difficult and time-consuming. Historically, this involved taking samples, transporting them to the lab, analyzing them, and then evaluating the data.

With the advent of modern technologies [Portable Ge detectors, compact electronics, powerful PCs] one person can carry a complete laboratory-quality Ge gamma spectroscopy system to the accident site, as part of the initial emergency response kit

Efficiency calibrations have been a traditional problem, but the ISOCS mathematical algorithms allow high quality calibrations to be done quickly in the field without any radioactive sources. This allows InSitu measurements to be done of large samples of food, vegetation, milk, water, soil, much more sensitively and accurately than small samples. People can also be quickly assayed in the field [or hospital] for internal/external contamination. And, traditional samples that must be taken can also be counted.

But, most importantly, high quality results are available immediately, to give to concerned management, politicians, and citizens.

I. BACKGROUND

This article is written from the author's perspective and previous experience with a variety of emergency situations. These have included TMI [from day 2 onward], Chernobyl, accidents and exercises at US nuclear power plants, and many crisis' where a very important person [customer, boss, ...] wanted the answer to a complicated problem right away.

Typical analytical questions that must be answered are:

- Is anything there?
- What is it and how much?
- Is it dangerous?
- Is it above our regulatory limits?
- What can I tell the customer/boss/regulator/press ?

Today's emergency response team typically relies on gross non-quantitative portable instrumentation to make these educated guess in the field, and then substantiates them by sampling and laboratory analysis. That has served the industry well in the past, as plenty of qualified and experienced health physicists were available to respond to emergencies. And, generally, adequate time was available to evaluate and present the results. But today's HPs have much less experience with "uncontrolled" situations, and today's management/regulator/press wants results instantaneously, and they had better be right.

The ISOCS [InSitu Object Counting System] instrument to be discussed here is another tool for the emergency response team to use. This tool will give quantitative nuclide-specific results for a wide range of measurement conditions. Because it uses a Germanium detector, it is very easy for the operator, and the software, to determine exactly what radionuclides are being detected. For simple cases under controlled temperature conditions, and with experienced operators, NaI spectroscopy might suffice, but real emergencies can't be planned this way.

Conventional mobile laboratories use Ge spectroscopy, and can be driven to the accident location rather quickly. But, they are large in size, and still require the sample to be found, extracted, packaged, prepared for counting, and then analyzed. Portable Ge systems, like ISOCS can

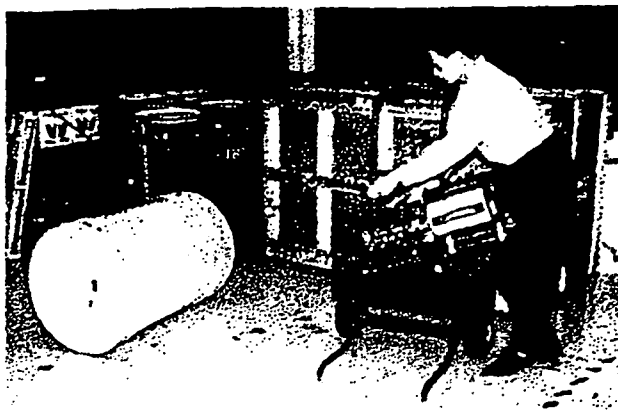


Figure 2 ISOCS used to measure drum.

In-situ Ge gamma spectroscopy measurements provide many advantages over the traditional methods of sampling, followed by laboratory analysis.

- Results are available nearly instantaneously. Then, reliable decision can be made about what to do next.
- Where the object is not homogeneous, the ISOCS results are probably more accurate, since a very large fraction of the object is measured;
- Detection limits are as low or lower, since a very large sample size is used.
- Costs are typically lower;
- Risks/doses are typically lower, as less work with potentially contaminated material is done.

This is an ideal instrument for decontamination surveys, environmental measurements, emergency response teams, operational radiation protection surveys before maintenance operations, occasional use waste assay measurements, and regulatory inspection teams.

There are some cases where taking samples is the appropriate thing. This includes areas where access is difficult for the detector, items that are heavily shielded, or where samples must be taken for other types of analyses. Examples include air particulate samples, removable contamination assessment samples, subsurface soils, ... etc. For these cases, quantitative field assay using the ISOCS instrument still provides the benefits of quick turn-around, reliable analysis results, and the capability of handling many different sample types. Figure 3 shows the ISOCS instrument in a shield configuration for counting large Marinelli

beakers of sample. Here the back shield and a part of the side shield are used. The beaker with a large sample provides the rest of the shielding. Also shown, is the detector with both shield sets installed. This provides a fully shielded 10cm dia. x 15cm long sample cavity.

Since accidents cannot be predicted in advance, pre-defined counting geometries also cannot be pre-defined for all scenarios. The ability to react in the field to whatever situation is found is quite important to the emergency team. Field calibrations of counting instrumentation is historically quite difficult, as they involve transporting radioactive sources, and preparing them into field geometries, generally in unfavorable conditions. This is where the advantages of the ISOCS sourceless calibrations make field gamma spectroscopy very practical today.

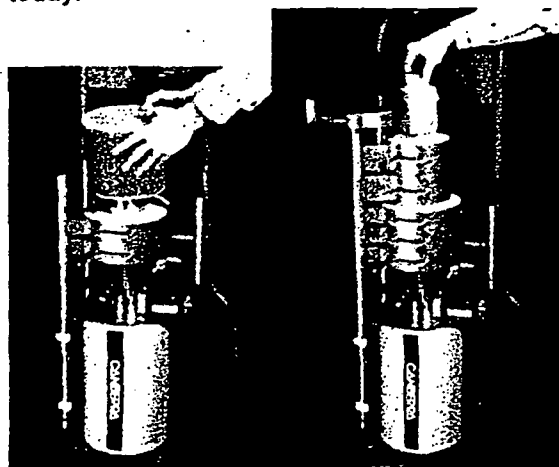


Figure 3 ISOCS used to assay Marinelli beakers and small sample containers.

The patented ISOCS method involves the use of MCNP for a detailed factory characterization of the response functions for each individual detector. Then, the user adds the final correction for modifying factors, such as sample size and density, container size and material and density, other absorbers, air temperature and pressure and relative humidity, any collimation, and distance and angle between the source and the detector. The efficiency is then computed at the user-specified energies. The source can be basically any size, from points up to hundreds of cubic meters. The source can be at zero distance from the detector, to as far away as 500 meters. The source can be at any location around the detector,

be used in this way, as a very portable sample counting lab. And, the same instrument can be used as an InSitu system, to bypass the time, expense, and sensitivity limitations of sampling, packaging, and sample preparation. It is the capability of performing efficiency calibrations in the field without radioactive sources that gives the ISOCS instrument such important value for emergency applications. Emergency situations are not predictable. Therefore, it is to be expected that unexpected measurement conditions will happen. In this day of "procedures for everything" it is important to retain the capability of flexibility to handle a wide range of situations, especially those that are not planned.

II. THE ISOCS INSTRUMENT

ISOCS is a portable Ge gamma spectroscopy instrument designed to both identify and quantify gamma emitting radionuclides in various sized and shaped objects. The ISOCS instrument consists of the following components:

- Ge detector of appropriate type, size, and shape for the application;
- Detector mounted in all-attitude cryostat so that it can point in all directions; typical cryostat holds 5 days of LN;
- Series of 25mm and 50mm thick shields each with various angle collimators to define the field of view of the Ge detector, and to reduce interference from other objects; these collimators can be configured for sample counting, or for in-situ counting;
- Sturdy and portable cart to allow detectors and shields to be transported to the measurement site and to aim the detector at the objects to be measured, or to count samples taken from the objects;
- InSpector, a portable battery-operated electronics package that includes HVPS, amplifier, ADC, and MCA, all controlled by the computer;
- Laptop Computer, also battery operated, for data analysis and storage of the spectrum;
- Genie2000 Gamma Spectroscopy software to convert the spectrum into identified nuclides and their activity and/or concentration;
- ISOCS mathematical efficiency calibration software to allow quantitative analysis of a wide variety of in-situ and ex-situ samples.

Figure 1 shows the basic detector, shield set, and carrying cart. Mounted on the detector is the 50mm thick shield set, with the 25mm thick set on

the floor. Not shown is the tray which carries the unused shields

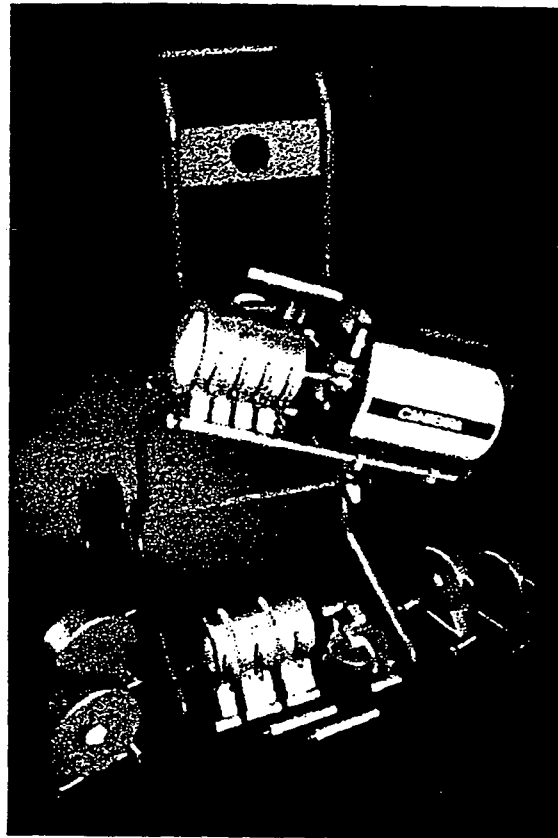


Figure 1 ISOCS detector and shield set.

With this new portable instrument, the user can now measure the radioactivity content of complete objects, large or small, or samples from these objects. For in-situ applications, the detector is aimed at the item to be assayed. Figure 2 shows the ISOCS used to measure a barrel lying on the ground, simulating a typical accident or D&D application.

from the front, to the back. Collimators are supported, both rectangular and cylindrical.

Independent validation comparisons have been performed with approximately 10 different detectors and approximately 150 different geometries, each with approximately 10 different energies. These show accuracy in the 4-8% sd range.

III. EXAMPLES OF ACCIDENT / INCIDENT SCENARIOS WHERE IN-SITU GAMMA SPECTROSCOPY IS IMPORTANT

A. Suspected airborne release from NPP.

Here the traditional method is to take gross measurements in the field, take many samples, and report the results to the public several weeks later with the analyses are done. But, with ISOCS, the response team can count the ground surface directly and show quantitatively what is [or is not] there. Instead of taking small milk samples, count the entire milk truck. Instead of taking small samples of edible crops, count large bags or pallets of them in place. Count the air gas/particulate/iodine samples in the field, and report only the nuclides of interest, not radon daughters, not xenon or iodine samples.

B. Transportation accident

Here, a truck is in an accident and is overturned, spilling the contents on the side of the highway. There are several boxes with radioactive materials labels on them. The outside of these boxes are wet. The ground is wet. Is this a radioactive materials contamination problem? In-situ analysis of the soil and the truck will help provide the answer. Field sample assay of the shipping boxes can also be performed. This, combined with traditional gross beta/gamma survey instruments can quickly arrive at the correct answer for most of the situations.

C. Alarm on truck monitor at scrap steel yard or landfill site.

What has caused the alarm to go off? The truck monitor is a gross instrument, and responds to many things. Is this alarm just some soil with more thorium than normal, or is this a real public health concern? This is an excellent application for ISOCS. Just aim the detector at several locations along the side of the truck, as shown in Figure 4. Calibrations are quite simple and then

not only will the nuclides be known, but also an estimate of the concentration.

This same counting geometry could be used by a prudent D&D contractor to prove that their "clean" construction debris really is, or for the local/federal regulatory authorities who are providing independent monitoring to assure that the public is protected.

D. Accident at where worker is injured and contaminated

Most large NPP and DOE facilities have good WBC systems to assess internal contamination, but many other facilities do not. But, for all cases where the worker is injured, the first priority is to take care of the injury, not to get a whole-body count. The ISOCS instrument is well suited for this application, as it is small enough to take to the hospital. It is flexible enough to be used to count thyroid, lungs, total body, and wounds. The mathematical calibrations can also be used for these unusual geometries. The counter can also be used for hospital and attendant personnel to assure that they are not contaminated. The same instrument can be used to provide in-vivo assessments of members of the public or hospital staff where suspected contamination from patient treatment or an accident has occurred.



Figure 4 ISOCS Used to Monitor Truck or Trash Container

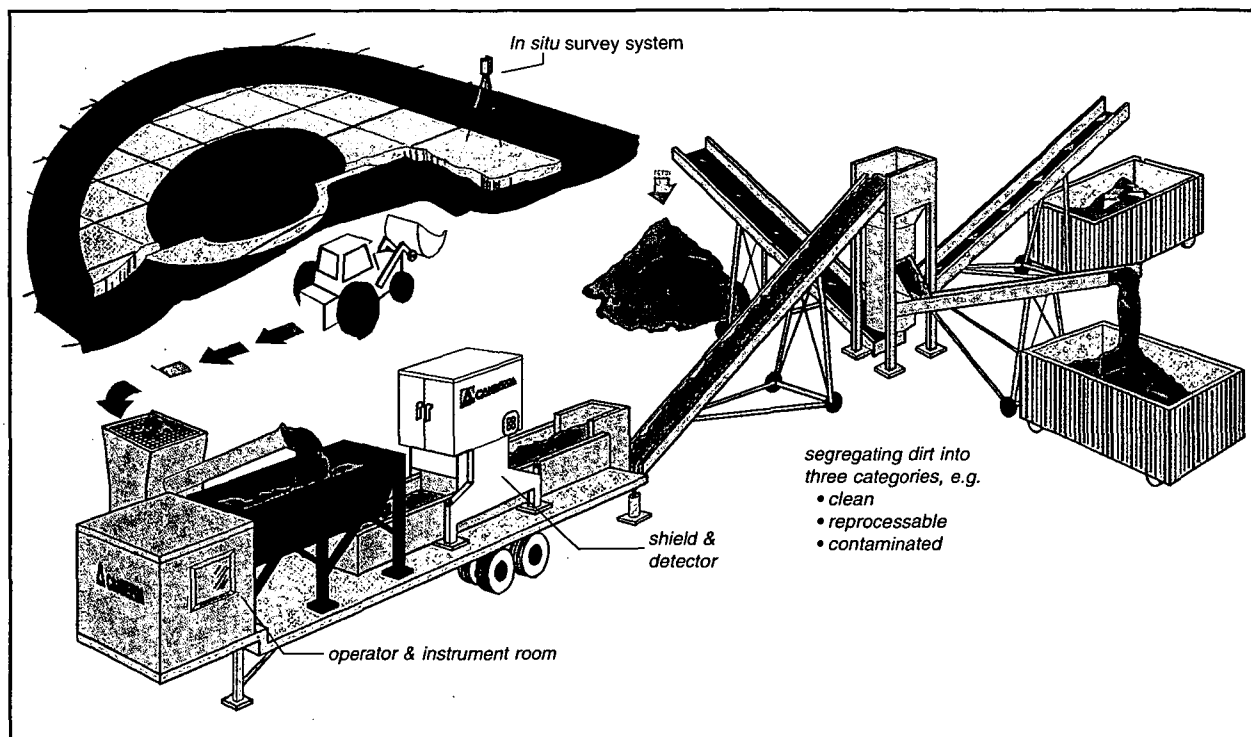
E. Evaluation of suspected past releases from radioactive materials sites

Examination of past records often shows that large quantities of materials have been released from sites, but does not provide adequate documentation showing that these were not contaminated. In-situ gamma spectroscopy with ISOCS is quite valuable to search for large areas of property to find it, or to prove that it is not present. When small amounts are found, the use of the gamma spectrum to place the amount found into perspective by comparison with the natural Radium, Thorium and K-40 has also proven quite useful.

IV. CONCLUSION

The use of in-situ Ge gamma spectroscopy is a valuable tool to add to the arsenal of the emergency response team. It is small, and easy to transport. It is easy to use, and provides reliable nuclide-specific results. It provides these results quickly to the radiation protection professional in the field, so that he and others can quickly make the proper assessments and report them to all the other interested parties.

Canberra... Solutions for Environmental Remediation



If you have a contaminated soil problem, we have a
New, Innovative, Integrated solution

In situ
high resolution
field gamma
spectroscopy

+

Nuclide-specific
automatic
conveyor
dirt sorting

=

- Less radioactive waste
- Lower project cost
- Earlier project completion
- Better project documentation

The *In situ* Soil System provides the preliminary characterization to guide the excavation.

Canberra's Automated Conveyor Soil Monitor can then be used to characterize and segregate clean from contaminated dirt.

- Reduces contaminated volume from 25 to over 75%
- Reduces false alarms with nuclide-specific results and release levels

- Separates waste into three output streams
 - “clean”, for low cost disposal
 - “somewhat contaminated”, but perhaps suitable for volume reduction schemes, such as soil washing
 - “contaminated”, for disposal as radioactive

Contact us for more information...



CANBERRA

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New tools and benefits for ER clients

Traditional Method

Survey & grid
Take surface samples
Take subsurface samples
Wait for lab results
Prepare excavation plan
Dig according to plan
Take samples to see if done
Wait for lab results
If not clean, dig again
Take samples, ship/dispose
Wait for lab results
Ship/bury/return to ground

New Tool

In situ high resolution field gamma spectroscopy
• Ge detectors
• Global Positioning System
• Geographic Information System

Benefit

No surveying needed
Minimum sampling
Lab quality field γ -spec
Large "sample"
No *chain of custody* problem
Immediate results

saves money
saves money
saves time & money
more accurate
more reliability
saves time

New Tool

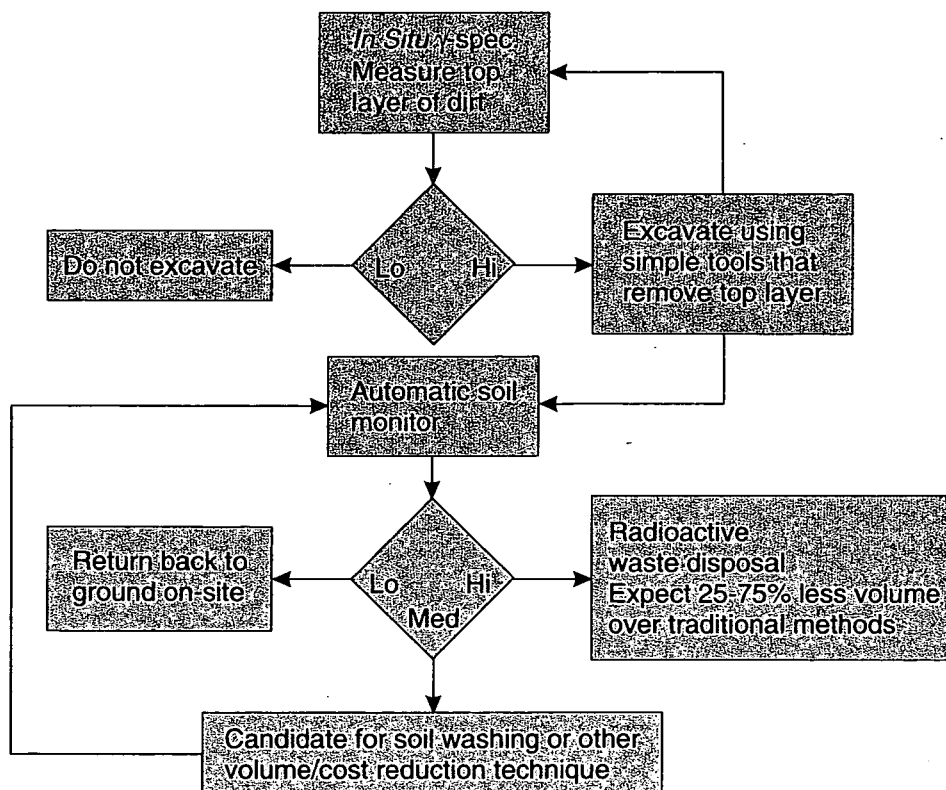
Nuclide-specific automatic conveyor monitor
• 50t/hr
• Ge detectors
• Full storage in database

Benefit

Minimum sampling
100% of dirt measured
Large "sample" viewed
Full gamma spectroscopy
Ge gamma spectroscopy
Immediate results
No *chain of custody* problem

saves money
more accurate
more defensible
more accurate
action by nuclide
detects most nuclides
internal QA record
saves time
more reliability

Flow plan of dirt ER



Automatic Conveyor Monitor for Soil and Debris

Features

- Automatically assays soil, rubble, and debris, and sorts it by activity
- Saves both time and money by making site decontamination a continuous, rather than batch, process
- Conveyor speed and material depth controls allow processing rates from 1 to 50 tons per hour
- Dual Germanium (Ge) Detectors provide a typical sensitivity of 1 pCi/g for Ra or K in soil, and 0.1 pCi/g for ^{137}Cs and ^{60}Co in normal soil
- 15 cm low background steel shielding used throughout
- Adjustable shield shutters allow material depths from 5 to 30 cm for flat bed conveyors
- Trailer mounted for easy transportation to, from, and around a job site
- Conveyor/Detector designed for operation outside
- Separate environmentally controlled operator/instrument control room

Description

The Automatic Soil and Debris Conveyor Monitor can easily reduce by half the time, effort, and expense required to clean up a contaminated site. To see how, compare the procedures that must be performed using the traditional approach to this new method of contamination remediation.

The Traditional Approach

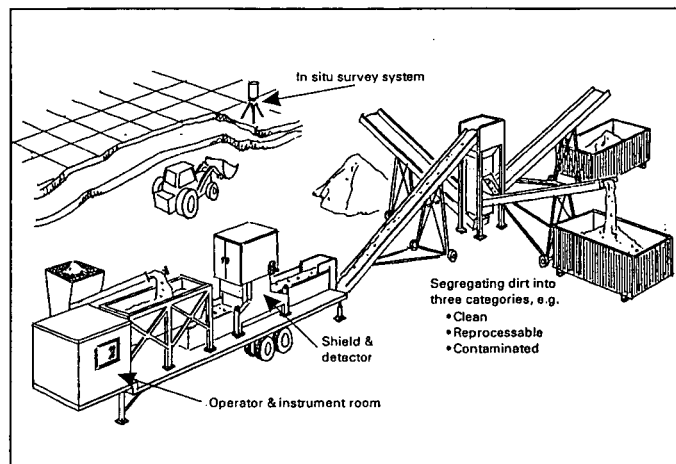
Traditional soil decontamination can be a very slow and expensive process, for it requires multiple samples to be taken and analyzed, and all of the soil to be handled at least twice:

1. First you need a detailed site survey and excavation grid plan.
2. Next, each block in the grid must be sampled and analyzed to determine if it needs to be excavated. This is commonly done at various levels for each grid point, making it very expensive and requiring several months to get the results.
3. Now each contaminated grid must be excavated and the soil temporarily stored.
4. Each stored batch is then sampled and analyzed to determine its activity level, and then moved for proper disposition.
5. For the soil remaining under each block that was excavated, start again at step 1 to insure that sufficient soil was removed.

The New Method

Extensive detailed sampling is not required, and the soil and debris need only be handled once.

1. Using high resolution, high sensitivity Ge detectors, perform an *in situ* survey of the top layer only, using a coarse grid. Canberra's *in situ* system is pre-calibrated, and gives instant results.
2. For each contaminated section, excavate a layer of soil, and segregate it by radioactivity level for disposition in real time. Since the counter is automatic, excavation of some extra "clean" material in the process does add more disposal volume. Perform another coarse grid *in situ* survey, and remove another layer if necessary.
3. Perform a final *in situ* survey to insure that all contaminated material was removed.



Typical Conveyor, Shield, and Detector Assembly System Set Up.

The net result is a significant reduction in the time and effort required to clean up a site. And the material is separated into 2-3 different streams to minimize the ultimate disposal costs. Unlike statistical sampling techniques where only a small sample is assayed, 100% of the soil is assayed, and with the same high quality gamma spectroscopy tools that would have been used in the laboratory. This greatly improves the quality of the data for non-uniform contamination.

THE CONVEYOR, SHIELD, AND DETECTORS

The Conveyor, Shield, and Detector Assembly for a typical system are shown above.

Input Material Processing

The soil to be counted is generally screened to remove large items such as rocks and vegetation, although these can be processed and counted if desired. This capability can be supplied by Canberra or provided by the customer.

The Counting Conveyor

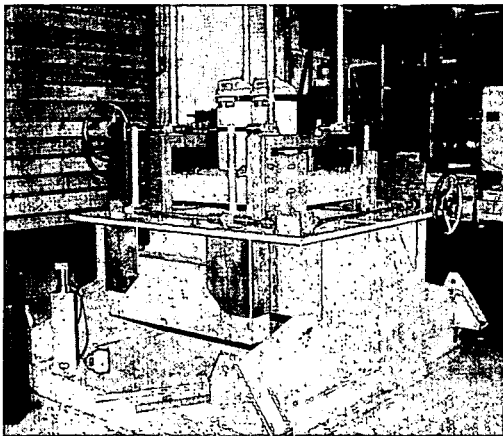
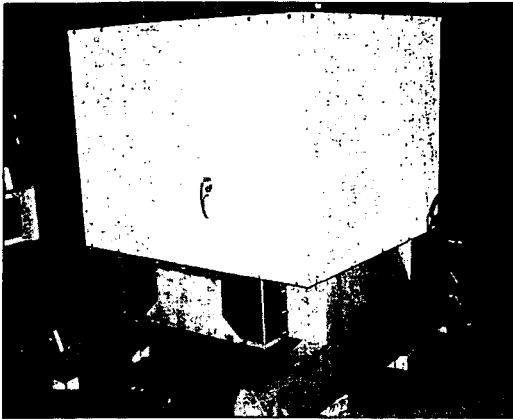
The typical conveyor used here has a 76 cm wide flat belt unit under computer control. By controlling the depth of the material on the conveyor as well as its speed, the throughput may be set to any desired rate from 1 to 50 tons per hour. Special techniques are used to clean the belts, to minimize dust, and to monitor for residual contamination in the belt.

The flat belt design is preferred, for it allows the entrance and exit shutters of the counting chamber shield to be positioned more closely to the soil and debris as it is being transported. In the usual conveyor configuration, a diverter mechanism on the conveyor's output is used to steer the assayed material to cold, low level, and high level containers or trucks.

The Shield

The shield supplied with the counter is made of 15 cm thick low background steel free from ^{60}Co , and weighs approximately 10 000 kg. At the soil entrance and exit adjustable shutters are used to bring the shield down to just above the level of the material. These shutters are adjustable for material depths from 5 to 30 cm.

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The Detectors

In its standard configuration the system is supplied with two Germanium detectors in a vibration isolation mounting. The height of the mount is adjustable to compensate for differing soil depths and activities. For a typical installation these detectors yield a sensitivity of 1 pCi/g for Ra and Th, and 0.1 pCi/g for ^{137}Cs and ^{60}Co in normal soil, assuming a one minute count time.

Environmental protection for the detectors is provided by a plastic dust shield located between the detectors and the soil, the use of LN_2 vent gas as a dry air purge for the detector chamber, and a moisture resistant covering on the preamplifiers. Then, the entire electronics are enclosed in an environmental enclosure.

The system is also available with dual large NaI(Tl) detectors for those situations where the lower resolution of these detectors is not a problem.

Output Conveyors

After leaving the counting conveyor, the material is sent to the diverter gate. When the analysis is complete, and when the leading edge of the sample reaches the diverter gate, the computer instructs the diverter to send the material to one of three pathways. For example, high level material can be sent off site for disposal or placed in a high integrity on-site disposal cell. Medium level material can be sent to a less expensive off-site location, or perhaps used for the top of the disposal cell. Low level material can be used in an unrestricted manner anywhere.

SYSTEM ELECTRONICS

Signal Processing

Computer-controlled ICB NIM are used as the signal processing electronics for the detectors. They connect to the system's Host PC via an Ethernet link and provide the ability to manage all signal processing remotely from the Host.

Programmable Logic Controller

A programmable logic controller (PLC) handles all conveyor and diverter control and monitoring. The operator's control station also ties into the PLC, and a communications link is provided between the PLC and the Host PC.

SYSTEM SOFTWARE

The powerful Genie basic spectroscopy package serves as the base for the system's software. The application software which runs on top of this base utilizes Canberra waste management analysis algorithms and techniques that have proven their effectiveness in scores of installations.

The results from the assay software are used to control the output diverter of the conveyor via the PLC. In addition, all results are stored in a relational database to insure that a defensible record of all of the work is maintained.

PERFORMANCE

The performance varies with the details of the system configuration, ambient background, sample makeup, and counting time used. The following outlines what can be expected for a typical system installation.

SAMPLE HANDLING

The following assumes a 76 cm conveyor width and the sensitivity level described in the next section.

- THROUGHPUT – 1 to 50 tons per hr.
- SAMPLE DEPTH – 5 to 30 cm for flat bed conveyors

MINIMUM DETECTABLE CONCENTRATIONS

Assumptions

- Dual Germanium Detectors, 25% relative efficiency
- 0.01 mR/hr. Ambient Background
- Normal Ra/Th/K content in the soil
- One minute Count Time

Results

- 1 pCi/g for Ra and Th
- 0.1 pCi/g for ^{137}Cs and ^{60}Co

ENVIRONMENTAL

Conveyor and Detector Assembly

The conveyor and detector assembly may be operated over a -5 to 40°C temperature range. An environmental enclosure is provided to shelter the detection equipment from inclement weather.

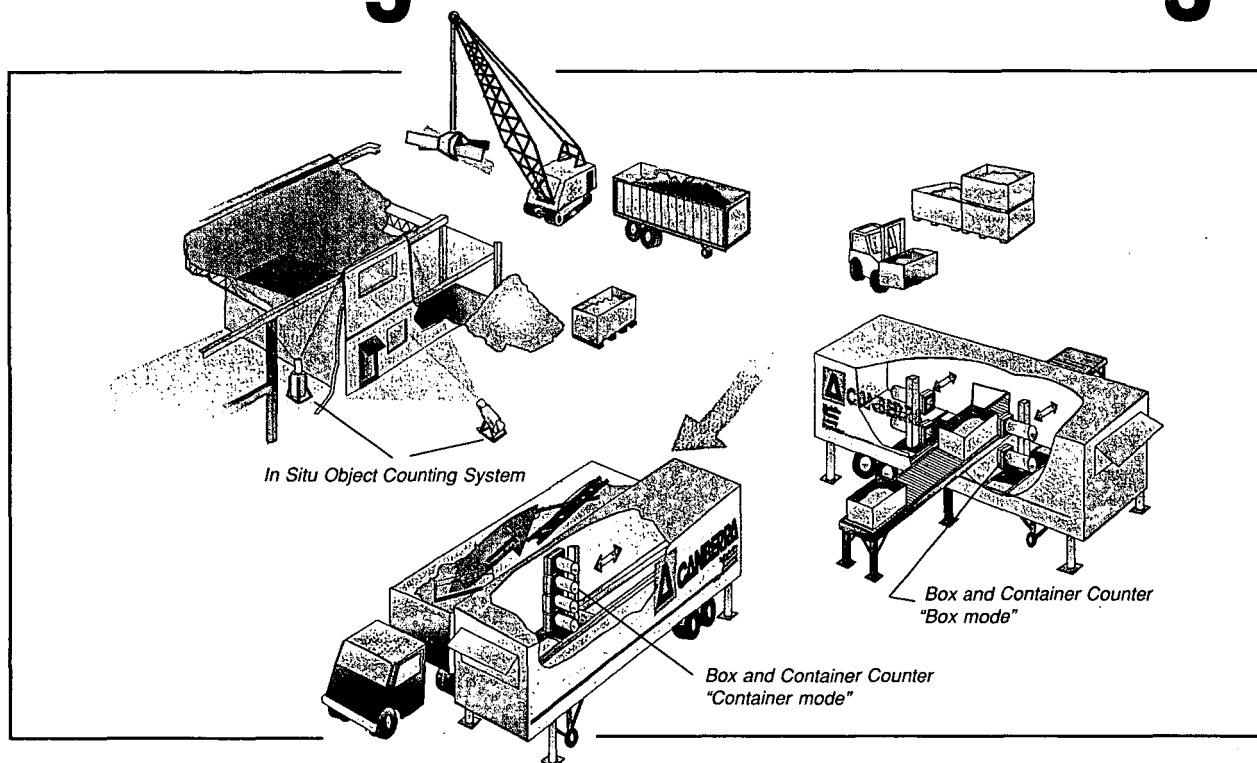
System Electronics and Host Processor

An environmentally controlled operator/instrument control room is provided.

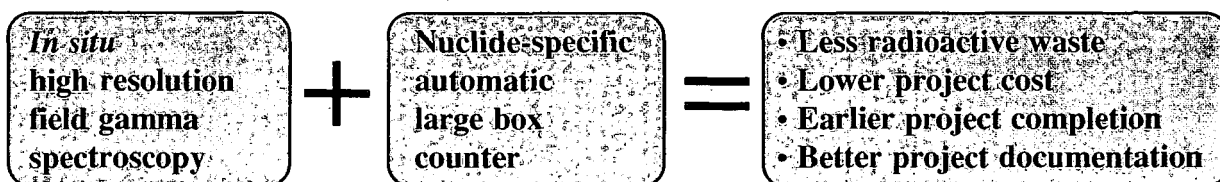
Mechanical

The sample distribution conveyor, sample counting conveyor, shield, and instrument control room are all mounted on a single 40 foot trailer. The output conveyor and diverter gate are shipped and mounted separately. Other input processing equipment and input and output conveyors can be supplied by either Canberra or the customer.

Canberra... Solutions for Building Decommissioning



**If you have a contaminated building problem, we have
a *New, Innovative, Integrated* solution**



The *In situ* Counting System provides the initial characterization of the building. Contaminated areas or objects are either cleaned or placed in boxes for shipment as radioactive waste. Clean areas or objects are either left in place, or demolished and transported for low cost disposal.

The Box and Container Counter Systems count a wide variety of sample sizes from boxes to tractor-trailers to prove that the initial characterization was correct, and to generate an official record or manifest.

- Saves labor in building characterization and demolition.
- More accurate than sampling and lab measurements.
- Proves that items "likely to be clean" really are.
- Works with containers from 1 - 35 m³.

Contact us for more information...



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New tools and benefits for Building Decommissioning clients

Traditional Method

Survey & grid the building
Take fine grid samples/meas.
Take subsurface samples
Wait for lab results
Prepare demolition plan
Remove contaminated part
Take samples to see if done
Wait for lab results
If not clean, chop again
Take samples, ship/dispose
Wait for lab results
Ship/bury/send as trash

New Tool

In situ high resolution field gamma spectroscopy
• Ge detectors
• Shield
• Calibration software

Benefit

No surveying needed
Minimum sampling
Lab quality field γ -spec
Large "sample"
No *chain of custody* problem
Immediate results

saves money
saves money
saves time & money
more accurate
more reliability
saves time

New Tool

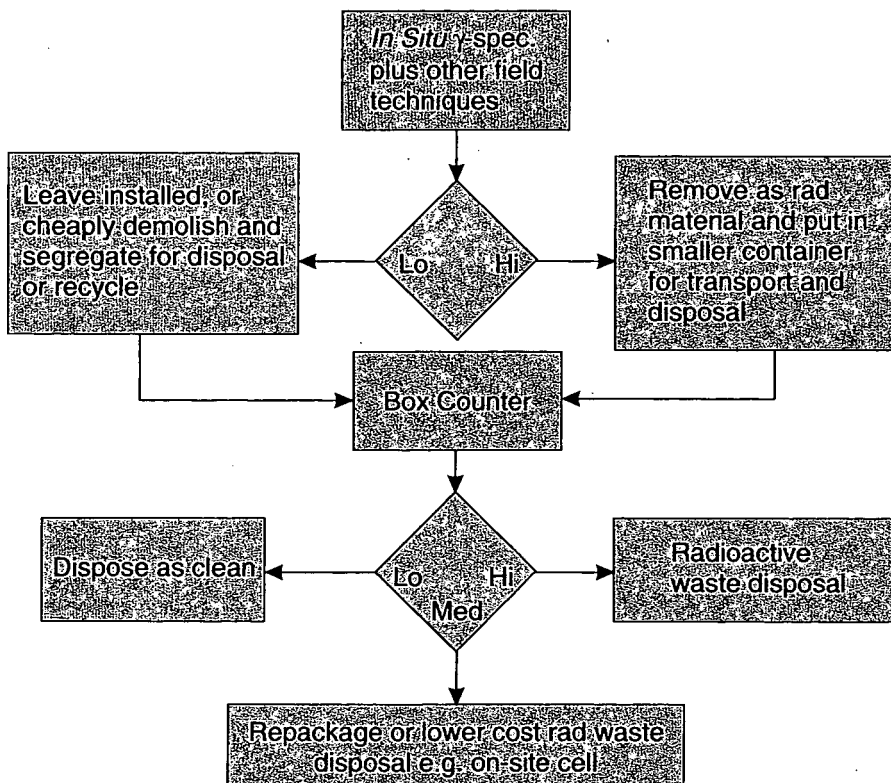
Nuclide-specific automatic large box counter
• 1-35 m³
• Ge detectors
• Full storage in database

Benefit

Minimum sampling
100% of object measured
Large "sample" viewed
Full gamma spectroscopy
Ge gamma spectroscopy
Immediate results
No *chain of custody* problem

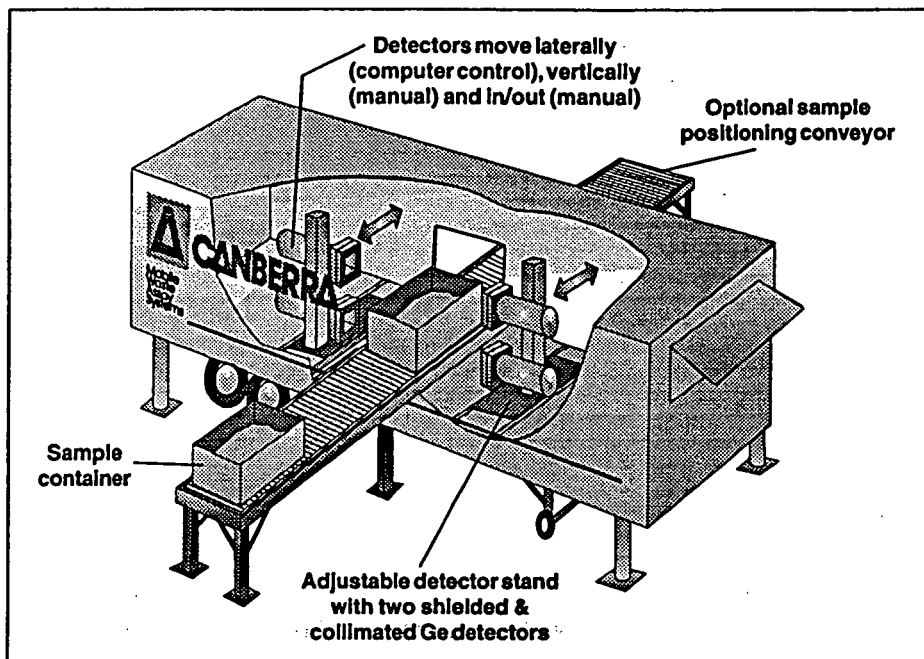
saves money
more accurate
more defensible
more accurate
action by nuclide
detects most nuclides
internal QA record
saves time
more reliability

Flow plan of building D&D



Features

- Performs full gamma spectroscopy and accurately characterizes containers of waste.
- Saves time and labor by assaying waste in a large container or its shipping container.
- Modular design can be configured for samples from B-25 (1x1x3 m³) boxes through ISO shipping containers.
- Fully assays a B-25 box in 30 min. and an ISO container in 2-3 hours.
- 0.01 Bq/g (0.3 pCi/g) typical detection limit for a B-25 box.
- Available with manual, powered, or automatic conveyor systems for sample handling.
- Multiple Germanium detectors (typically four) feature:
 - Adjustable detector height to match sample size.
 - Adjustable detector-to-sample distance to handle low or high activity samples.
 - Computer controlled lateral motion to count the entire container.



Typical box counter configuration in mobile laboratory.

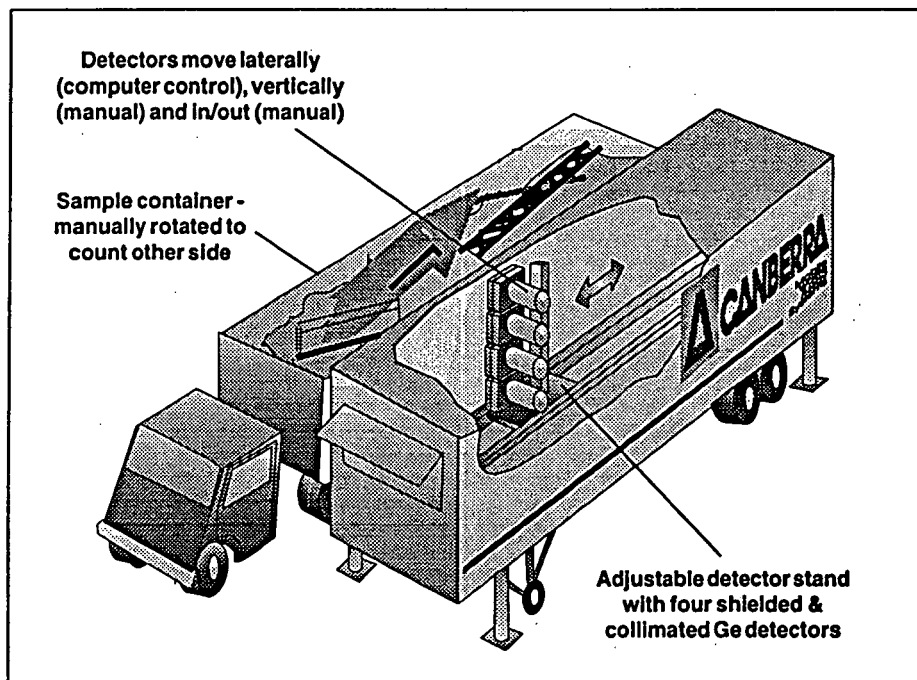
- ICB-NIM electronics for remote system control.
- Network access for remote interrogation and management.
- Utilizes a wide range of data correction tools for accurate results.

Description

The Modular Gamma Box Counter reduces the time and labor required to process waste by giving you the ability to assay it in shipping containers too large to be handled by traditional waste assay systems. Standard B-25 boxes (typically 4 x 4 x 6 ft) can be assayed to a detection limit of 0.3 pCi/g (typical for nuclides >300 keV and 100% yield) in as little as 30 minutes, and a full sized ISO shipping container (typically 8.5 x 8 x 20 ft) processed in two to three hours. Compared to the alternative of unloading the container and/or counting the contents individually, significant savings in handling time and labor can be readily achieved. And, since a very large fraction of the container is analyzed (much larger than traditional sampling techniques), a more accurate result is commonly obtained for those samples with non-uniformly distributed radioactivity.

Modular Design for Flexibility

The counter utilizes a modular design, allowing it to be easily adjusted to handle a wide range of sample sizes and shapes in the optimum configuration.



Typical installation to assay large waste containers.

Movable Detector Assemblies

Movable Detector Stands, adjustable for both sample height and size, are the key to the counter's flexibility. Position them on either side of a sample stand or optional conveyor, and you have a system configured for processing boxes. Or, use one - with all four detectors on it - at one side of a covered loading platform, drive up a truck with a shipping container, and the exact same system can be used for assaying full sized ISO shipping containers.

The standard detector stands are manually adjustable for detector height and sample: detector separation. The counter will move the detector assembly laterally along the entire sample length during the count to measure the entire sample. The individual measurements along the sample length and height are also used to determine sample non-uniformity.

For lowest cost, a simple manual stand is also available. This can be used with just one detector, with the necessary sample segmentation provided by moving the sample manually.

Germanium detectors are used because they are much less sensitive than NaI(Tl) detectors to changes in the ambient environment. In addition, the superior resolution of germanium detectors is a major benefit in handling the complex multi-nuclide spectra often found in waste material.

Each detector is housed in a shielded and collimated module to minimize the interference from environmental and plant background. Shadow shields can also be provided if interference from nearby sample containers is a problem.

Each detector stand can hold two detector modules, with four detectors per system being the most typical configuration.

When very accurate matrix corrections are required, transmission sources, shields, and shutters can be provided (as an option) opposite the detector stands to allow transmission measurements to be made.

Versatile Sample Handling

The modular design of the system gives it an extremely versatile sample handling capability.

For low volume box counting, a simple sample stand or just a fork lift to position the box may be all that is required. For greater throughput, both manual and powered conveyors are available. Automatic powered conveyors that can load each new sample and remove the one just counted are also available. Manual or automated weighing systems can also be provided for matrix correction routines and for the calculation of the results in concentration levels as well as activity.

When the system is configured for large shipping containers, a truck is usually used to move the container into position for counting. Multiple lateral segments are automatically measured as the system repositions the detector tower along the length of the container.

Computer Controlled Electronics

The modularity is also carried over into its signal processing electronics. ICB-NIM is used throughout, giving you the ability to manage all of the system's electronics remotely from the Host PC.

Powerful Software Base

The software in the Host PC is built upon the powerful OS/2 based Genie-PC basic spectroscopy package. Using the REXX programming language and the Genie-PC Graphical Batch Tools, this base was then extended into an easy-to-use menu-driven application tailored to the job.

For manual systems, operator prompts are used for any needed geometry changes during an assay. Systems with automatic sample handling mechanism automatically perform the needed motion controls.

Proven Analysis Algorithms

In addition to the basic gamma spectroscopy capabilities associated with the Genie-PC, the final package also features Canberra's field-proven waste assay software function, including:

- Monte Carlo techniques for system calibration.

- Differential peak absorption.
- Transmission matrix absorption.
- Matrix density correction.
- Random summing and live time correction.
- Bilateral counting geometric averaging.
- Non-homogeneity identification from segment count rate data.

Performance

The performance varies with the details of the system configuration (number and size of detectors), ambient background, sample matrix, nuclide, and counting time. The following outlines what can be expected given the assumptions below, which are based upon a typical system installation.

Assumptions

- Detector(s) properly shielded and collimated.
- 0.1 $\mu\text{Sv/h}$ (0.01 mR/h) ambient background.
- Gamma energies from 300-1500 keV.
- 100% gamma abundance for the measured nuclides.
- 30 minute processing time for a B-25 box.

Sensitivity

Four Detector System

- Low density samples (0.3 g/cc): 0.01 Bq/g (0.3 pCi/g).
- High density samples (1.8 g/cc): 0.001 Bq/g (0.03 pCi/g).

Single Detector System

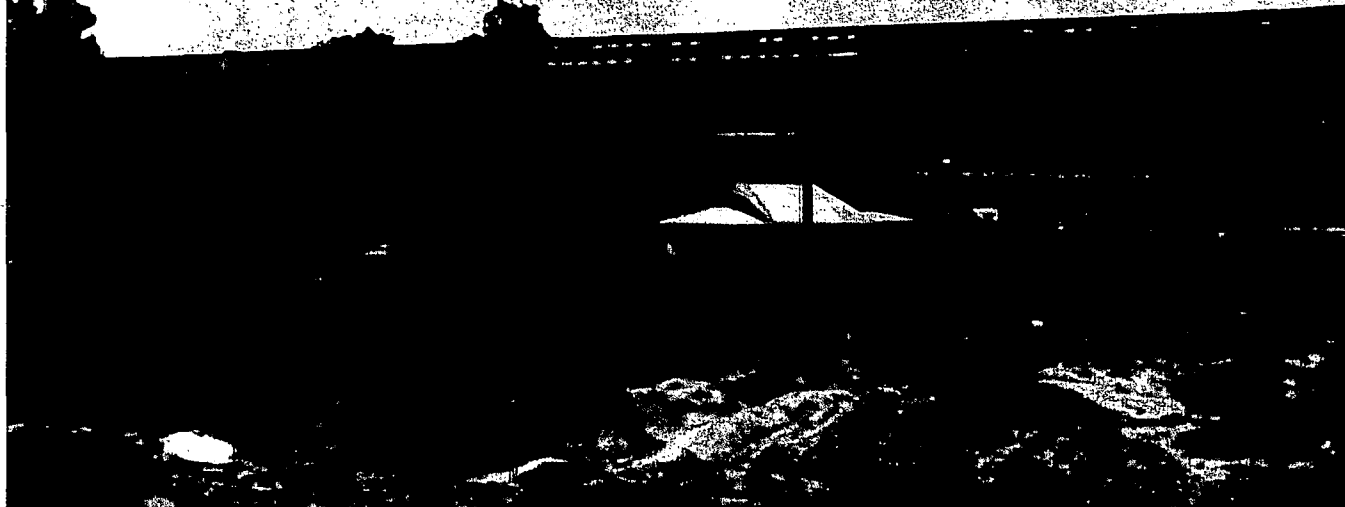
Since only a single detector is used, much greater sample handling is required to count all segments. This increases the sample handling costs, reduces the counting time at each segment, and raises the detection limits significantly.

- Low density samples (0.3 g/cc): 0.05 Bq/g (1.3 pCi/g).
- High density samples (1.8 g/cc): 0.007 Bq/g (0.2 pCi/g).

Environmental

- 5-35 °C, non-condensing humidity.
- Free from dust or other potential radioactive contaminants.

What Does Canberra Offer the D&D/ER Contractor?



Accurate & Affordable Results

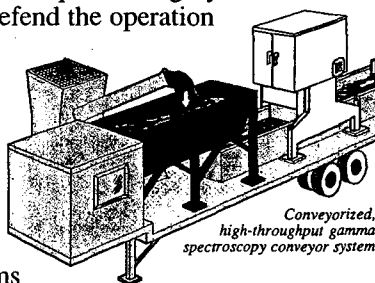


Canberra can be a valuable asset in every phase of D&D/ER — from project planning through closure. Talk to us early in the planning phase so we can show you how to save money. As the **Best In Class** supplier of nuclear measurement systems, we provide quality services and advanced radiation measurement instrumentation for the most cost effective operation.

We have the tools to characterize your site, separate radioactive from clean waste, classify radioactive waste into the lowest cost disposal category, and generate a database to defend the operation of your program.

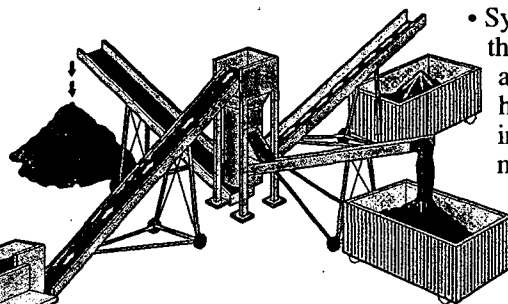
Canberra systems are available to support each phase of your D&D/ER project —

- *In situ* gamma spectroscopy systems for initial site assessment and final confirmatory monitoring of soil, buildings, or other objects. For large areas of ground, we offer multi-detector mobile systems with GPS. For below ground assessments, we offer narrow diameter well logging tools.
- Conveyorized, high-throughput gamma spectroscopy conveyor systems to characterize and sort bulk material [e.g. soil, crushed concrete, and



shredded building materials] according to radioactivity level.

- Gamma spectroscopy and neutron counting systems to measure and sort containers of waste. Container sizes can be standard 200 liter drums up to full sized ISO containers.

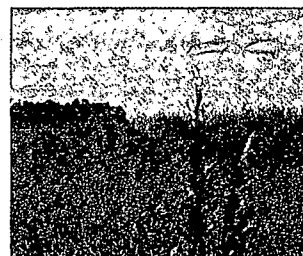


- Systems to protect the environment and workers' health. These can include alpha air monitors, automatic water monitors, fixed or mobile radiobioassay

laboratories, and fixed or mobile *in vivo* bioassay facilities.

- Accurate, verifiable and legally defensible database management systems for worker compliance records, and sample management records.

Whether you are interested in turnkey equipment or services, call in the results-oriented team. Call in Canberra... the one name you need to know for your D&D/ER projects.



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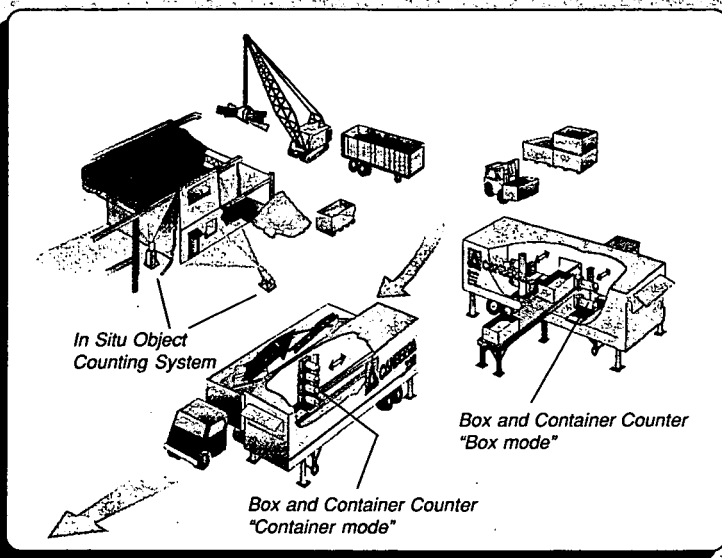
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Solutions for Site Restoration

Announcing two New, Innovative, Integrated Site Restoration Solutions using the same formula:

In Situ HPGe field gamma spectroscopy } + Nuclide-specific large sample sorting } = • Less waste • Lower cost
• Better records • Earlier completion

For contaminated building problems...

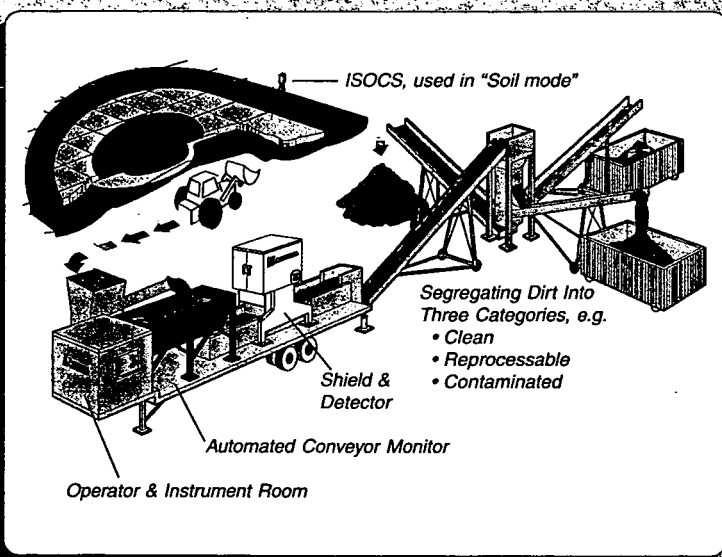


use Canberra's new ISOCS (In Situ Object Counting System) to do the initial characterization of the building. Don't waste money and time on sampling. Ge detectors identify nuclides and determine the activity for use in the D&D plan. After decontamination, use the ISOCS for final confirmatory surveys to prove that the building really is clean.

Contaminated building surfaces or objects are either cleaned or placed in boxes for shipment as radioactive waste. Clean surfaces or objects are either left in place, or removed with inexpensive techniques and placed in large boxes for shipment to low cost disposal facilities.

Then, the Box and Container Counting System is used to measure the boxes. The boxes can range in size from 1-35 m³. This provides shipping manifest data for the radioactive boxes. It also provides independent verification and a defensible record that the non-radioactive boxes really are that.

For contaminated dirt problems...



use Canberra's ISOCS in the soil mode to provide the preliminary characterization to guide the excavation. Don't waste money and time on sampling. Ge detectors are used to identify nuclides and to report how much is there. Use inexpensive techniques to excavate the dirt. Then measure again to see if it is clean. If not, excavate and re-measure, until done. It's all very fast.

Send the dirt through Canberra's Automated Conveyor Monitor to separate it into three different output streams based upon nuclide-specific activity from Ge detectors. Factors of 2-4 or more reduction in volume of radioactive dirt can be expected. Clean dirt can be returned to the site. Intermediate dirt is a candidate for soil washing. Capacities of 50 tons/hr are normal. And because the ACM is mobile, and well shielded, it can be placed close to the dig site.

For additional information call, write, FAX, Email, or stop by our Home Page...



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In Situ Gamma Spectroscopy with ISOCS, an *In Situ* Object Counting System

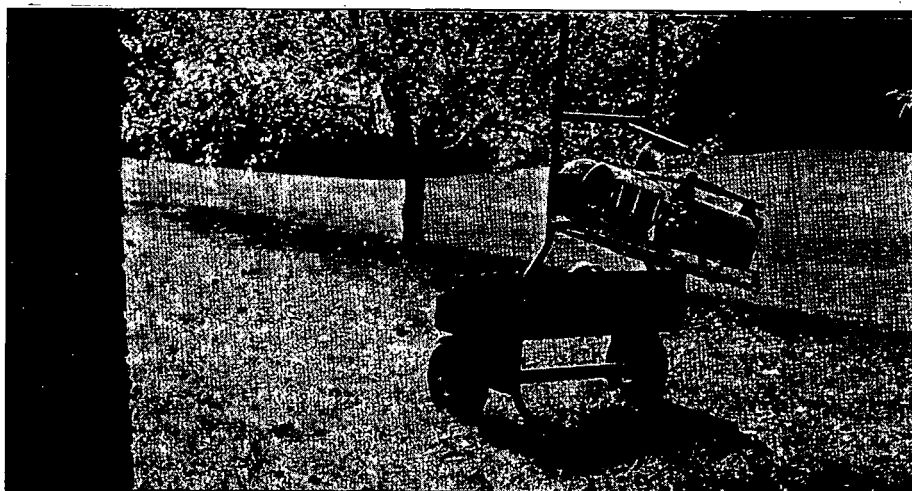
Now, Practical *In Situ* Gamma Spectroscopy

In situ Gamma spectroscopy is not new, but with the improvements in ISOCS, it is now a practical field tool to solve today's problems. And here's why:

- **Germanium detectors** offer stability and high resolution that cannot be obtained with NaI detectors.
- **Large Ge detectors** are now very common and affordable, and give excellent sensitivity with short counting times.
- **Canberra's MAC [Multi-Attitude Cryostat]** allows the detector to point in all directions and allows 2 day LN holding time. The **Big MAC** has a 5 day holding time.
- **The InSpector MCA**, when combined with a laptop PC gives laboratory quality gamma spectral acquisition, in a portable battery operated package.
- **Genie-PC**, our gamma spectroscopy data analysis package offers automatic and reliable spectral analysis.
- **The new ISOCS Shield and Stand** ties all of the hardware together, and makes it portable.
- **The new ISOCS Calibration Software** performs high quality efficiency calibrations for most all geometries without radioactive sources.

Typical ISOCS Applications

With its "go anywhere, count anything" detector and shield, battery powered electronics, and unique calibration software, ISOCS can be



used in a wide variety of *in situ* assay applications. Here are a few of the more common uses; for a more comprehensive list, see page 10.

Decontamination Assessment

Determination of near-surface ground contamination.
Determination of subsurface contamination by "well logging".

Building Contamination Assessment

Wall, floor, and/or ceiling activity measurements. Pipe and duct holdup measurements. Assessment of status of decontamination efforts.

Radioactive Waste Measurements

Measurement of nuclides and activity of boxes, bags, drums, and other objects. Free release measurements.

Environmental Monitoring

Determination of site natural background. Deposition following real or suspected accidents. Field assay of air particulate and iodine cartridges.

Public Health Measurements

Immediate results from the measurement of suspected contaminated areas.

Health Physics Measurements

Total room contamination [walls, ceilings, non-removable fixtures]. Determination of the cause for abnormal gross/doserate survey indications. Free-release determination of objects.

Nuclear Facility Maintenance

Identify nuclides in pipes or tanks *without* opening them. Quantify hard to sample residual activity from plateout.

Emergency Response Teams

Immediate answers to questions like "What and how much has spilled?", "What set off the gross counter alarm?", and "Is that wound contaminated?"

Regulatory Authorities & Inspectors

Analyze split or duplicate samples with licensee, compare results of sampling vs. total object measurement.

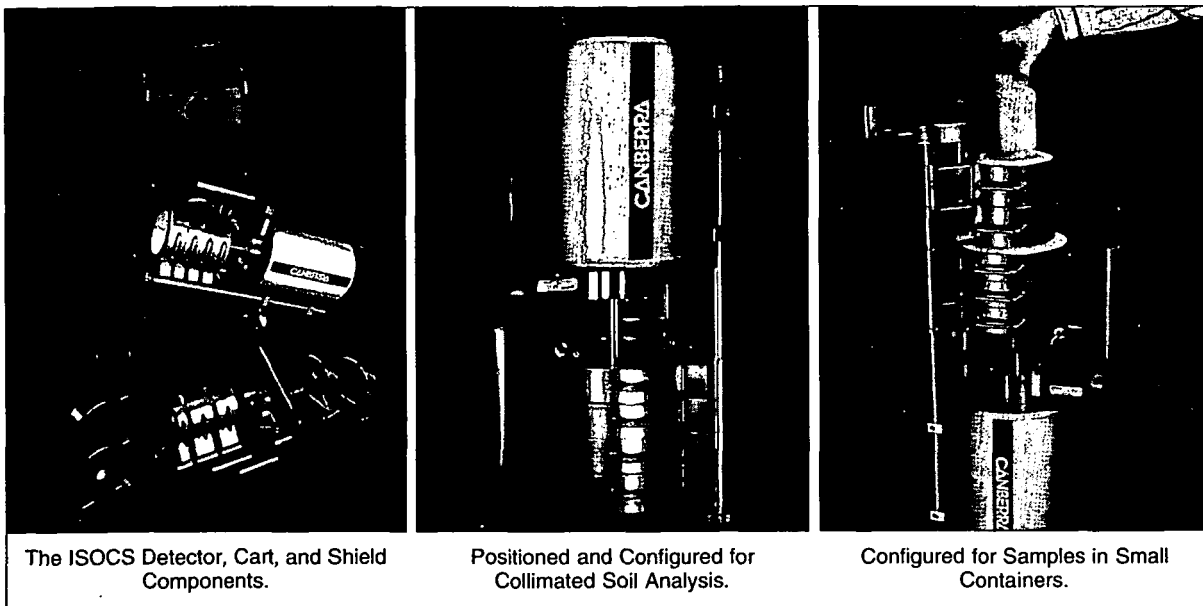


Figure 1

The versatile ISOCS Detector Holder and Shield can be positioned and configured to handle most any sample geometry.

The Benefits of ISOCS in D&D/ER Applications

Consider the problem of contaminated buildings and grounds. The three most expensive items in the decommissioning of buildings or grounds that are radiologically contaminated are:

1. The labor for the decontamination assessment,
2. The labor for the actual decontamination, and
3. The cost of disposing of the radioactive waste.

The time and labor cost needed to survey and assess a site can be greatly reduced by *in situ* assay because it:

- Eliminates the loop of field sampling, laboratory assay, more field sampling.
- Readily separates contaminants from naturally occurring radio-nuclides with high resolution Ge gamma spectroscopy.
- Provides essentially instantaneous qualitative and quantitative results that can be used to optimize the measurement and decontamination process.

In addition, since the inherent sampling errors associated with the sampling of non-homogeneous materials are minimized, you get both lower costs and better results.

The improved accuracy of *in situ* assay reduces these costs by minimizing the volume of waste that must be removed. This means that both the labor needed to decontaminate the site and the cost of waste disposal are greatly reduced.

The Canberra ISOCS System

An ISOCS system consists of the following major components:

1. An "ISOCS Characterized" Germanium Detector
2. A versatile set of Shields and Collimators on a Cart.
3. An InSpector Portable Spectroscopy Workstation.
4. An IBM-compatible Laptop PC running Genie-PC/2000 software with PROcount.
5. ISOCS *In Situ* Calibration Software.

A brief description of each of these can be found in the sections which follow.

The ISOCS Detector and Shield

The detector, shield system, and mounting cart, shown in Figure 1, are key elements to the unique versatility of ISOCS.

The Detector

While the typical ISOCS detector will be a coaxial Germanium with a relative efficiency of 40-60%, the design of the shield allows selecting the type – including low energy (LEGe) and reverse electrode (REGe) detectors – and size best suited to the specific needs of the intended application.

For greatest flexibility, the detector should be mounted in a remote detector chamber (RDC) cryostat and be equipped with a MAC or Big MAC Dewar. These Dewars have the ability for the detector to be operated at any attitude or angle with no LN spillage or reduction in LN capacity. The RDC allows the back-shield to be used, reducing interfering radiation. The MAC is smaller and has a two day LN holding time, while the Big MAC offers a five day holding time.

Once a detector is selected, it is fully characterized by Canberra using MCNP calibration methods. The results of this characterization are then utilized by the ISOCS calibration software, as described on page 4.

The Shield

The complete shield package includes both 2.5 cm (1 inch) and 5 cm (2 inch) lead shield assemblies. Each features:

- Modular design for ease of handling and reconfiguration.
- Steel jacketed exterior and epoxy lining to simplify decontamination.
- 30° and 90° collimators to minimize interfering radiation and limit the field of view.
- Top shield plate to make the shield into a closed sample counting chamber.
- Rear shield plate for use with RDC detectors to reduce interfering radiation from the behind the detector.

In addition, as shown above and in Figure 14 on page 8, the two shield sizes may be combined into a single shielded counting chamber for field assay of small packaged samples.

The Cart

The cart to which the detector and shield assembly are mounted is used for both moving the ISOCS system around the site, and as a mounting base when it is being used for sample assay.

As shown in Figure 1, the cart provides both the normal lower mounting position for the detector/shield, and an upper position for one meter *in situ* ground counting. It is very easy to move the detector and shield between the two positions.

The pivoting detector-holder mechanism provides the ability to easily rotate the detector and shield to any desired angle at either of the vertical positions, allowing the detector to be quickly "aimed" at objects of essentially any size, shape, or location.

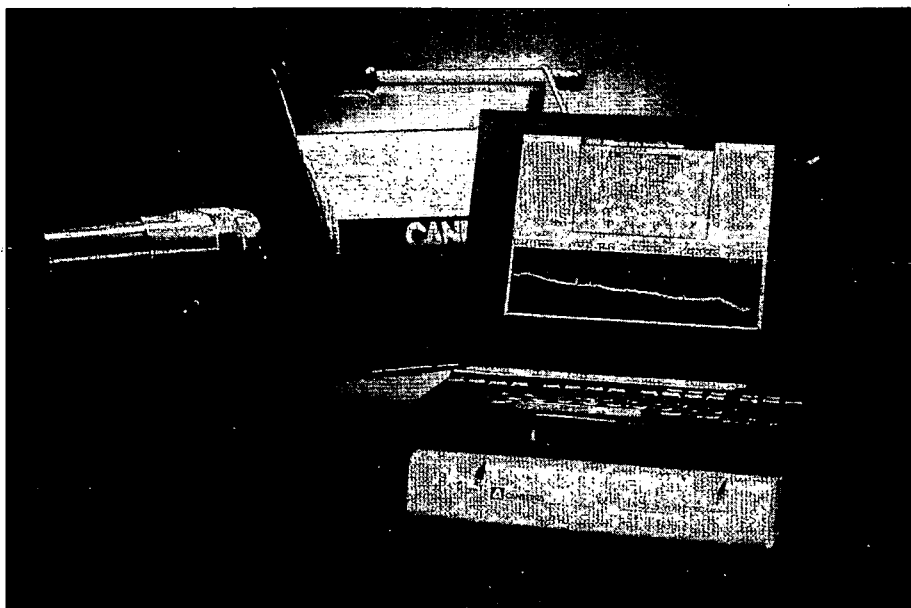


Figure 2

The Inspector MCA with its Laptop Control and Analysis Computer and Germanium Detector in a Big MAC Cryostat.

The detector holder also includes a battery operated laser aiming device to aid in accurately aligning the detector with the object being assayed. This is particularly useful for samples at some distance from the detector, such as overhead pipes.

The InSpector Portable Spectroscopy Workstation

The battery-powered Canberra InSpector MCA, mated to an IBM compatible notebook PC, serves as the spectroscopy workstation for ISOCS (Figure 2). For *in situ* assays it offers several major benefits:

- Lightweight (3.2 kg with batteries) compact design.
- Dual battery packs with "Ping-Pong" mode for uninterrupted counting.
- Complete laboratory grade spectroscopy front end:
 - Detector HVPS.
 - Spectroscopy Amplifier with PUR/LTC.

- Digital gain and zero stabilization.
- 8192 channel ADC and memory.
- Computer control of all operating parameters, insuring maximum accuracy with a minimum of effort on the part of the operator.

The net result is uncompromising spectroscopy quality in a small, lightweight package ideally suited to field use.

Genie-PC/2000 Software

The laptop PC which controls the system is under the supervision of the Genie-PC/2000 software package. With it, all of the capabilities of a laboratory based spectroscopy system – including the Spectroscopy Assistant's MCA View and Control and Gamma Analysis applications – are available in the field.

On top of this is added PROcount, a simple fill-in-the-blank counting procedure package for performing

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routine ISOCS operations. Using PROcount's step-by-step procedures, the operator is shielded from the intricacies of the computer, allowing full concentration on the job at hand (Figure 3). This insures more consistent results and greatly reduces the opportunity for procedural errors.

While PROcount makes ISOCS easier to use, it in no way limits the system's capabilities. Standard PROcount procedures are provided for all needed system operations, including:

- Routine Sample Assays.
- Background Counts.
- Energy and Efficiency Calibrations.
- System Quality Assurance.

There is also a password-protected facility for customizing these standard procedures; defining new sample types and geometries, setting up special sample information data entry screens, and building custom analysis sequences and reports.

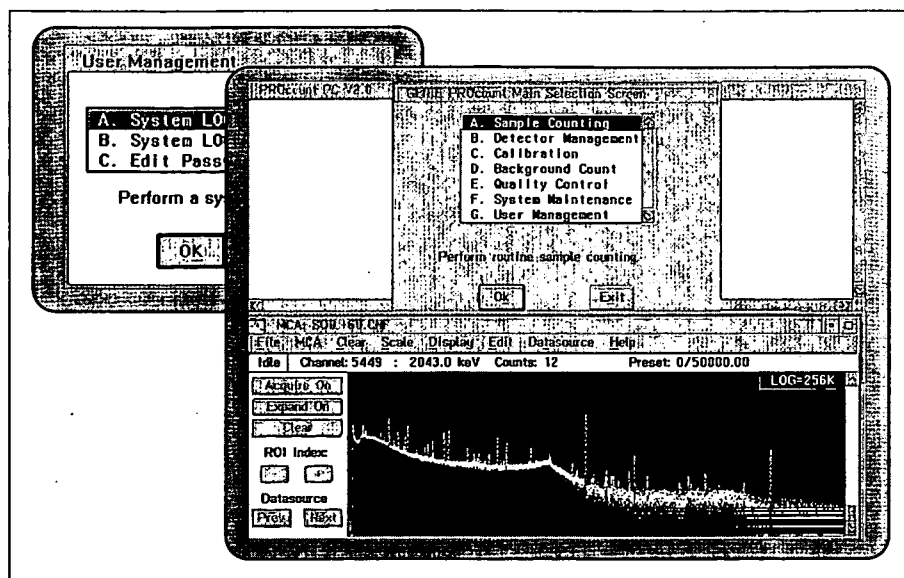


Figure 3
The Genie-PC with ProCount leads you through all assays with simple menus and fill-in-the-blank screens.

ISOCS Calibration Software

Accurate efficiency calibration is a must for any system being used for sample assay. Traditionally this has meant a major investment in the purchase (and later disposal) of a variety of calibration sources plus hours of calibration time and effort.

And each time a new geometry was encountered, a new calibration standard had to be prepared and new calibration runs performed. As you can see in Figure 4, with ISOCS and its unique calibration method you get the accuracy you need without this expense and effort.

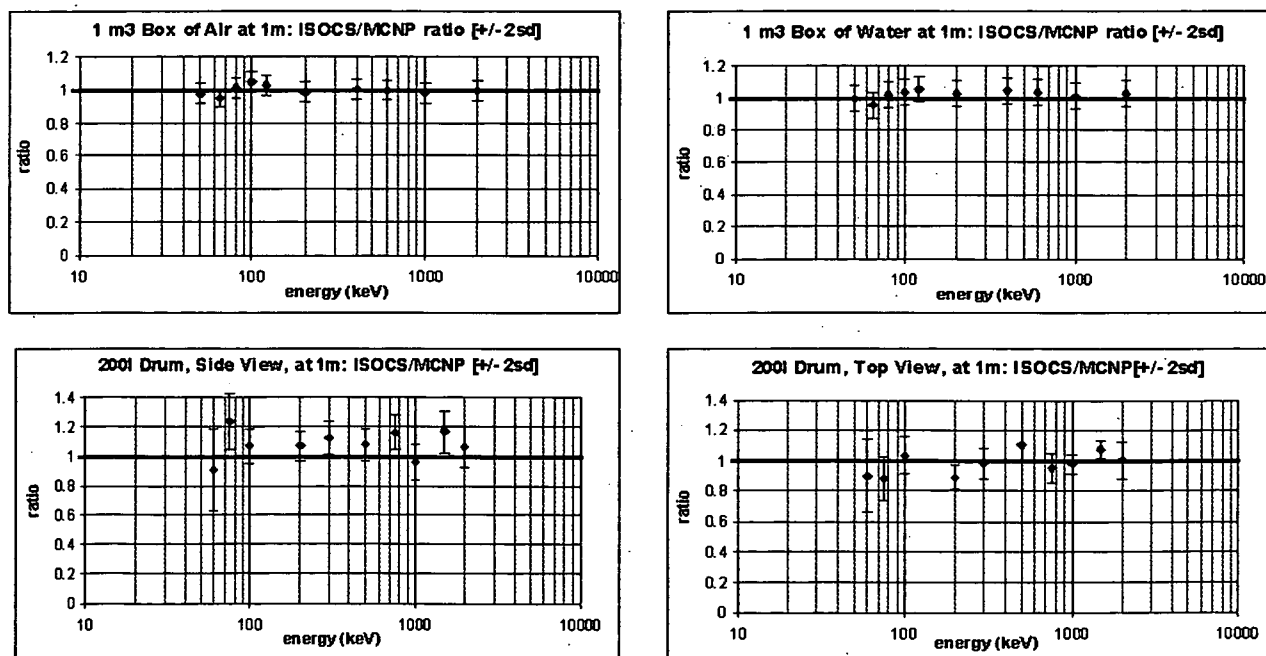


Figure 4
ISOCS and traditional efficiency calibrations typically agree within a few percent.

The calibration of an ISOCS system is a three step process:

1. Determining the response function of each specific Ge detector.
2. Defining a series of basic sample templates to cover the range of samples to be measured.
3. Selecting the detector, the collimator, and the template, and entering the parameters to describe the object.

Detector Characterization

This is done by Canberra, using the well-known MCNP Monte Carlo modeling code. Specifically, the radiation response profile of the detector to be used is determined for a 50 meter sphere about the detector over a 50 keV through 7 MeV energy range. The results of this characterization are delivered to the user in the ISOCS software. Multiple detectors may be characterized, and be available for selection by the ISOCS user.

The user may also select from a list of pre-defined ISOCS Shield Collimators.

Geometry Template Definition

This is also done by Canberra. Currently, ISOCS has nine standard geometry templates (see page 5) plus a choice of pre-defined shield collimator templates. Additional templates will be added as they are developed. If these aren't adequate for your application, custom templates can be created.

Parameter Entry

The easy part is performed by the user. By simply making a few physical measurements of the sample and entering them into the appropriate ISOCS calibration template, the source-detector geometry is defined. As shown in Figure 5, these measurements include things like the dimensions of the sample, the type and

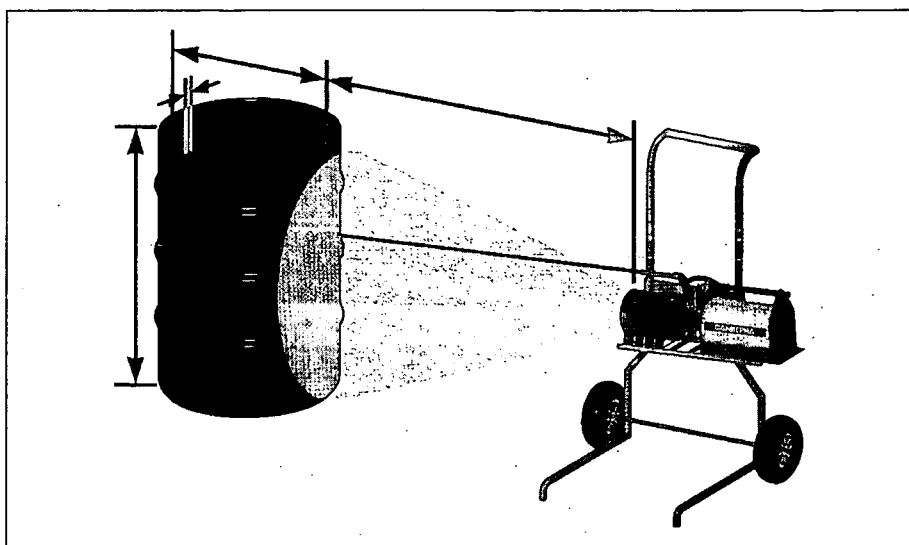


Figure 5

This is typical of the types of sample dimensions required by the ISOCS calibration software.

density of the material in the sample, and the distance from the detector to the sample.

This data is then automatically combined with the MCNP detector characterization to generate an efficiency calibration curve. This calibration, which is performed in a matter of seconds, can then be stored, used, and re-used just as if it had been produced by the traditional "custom source" method.

An additional benefit to this mathematical approach to calibration is the ability to easily play "What if?". For example, a series of ISOCS calibrations can be performed, each with the same sample dimensions but different sample density parameters. By using each such calibration in turn to assay the spectrum from a single sample count you can easily determine the impact of various sample matrices on the results of the assay. This can be an invaluable tool when you need to determine the assay error bounds for large, difficult to characterize samples such as boxes, drums, floors, and walls.

Sample Types and Geometries

At the present time ISOCS comes with nine standard geometry templates. Each of these templates can be modified by the presence or absence of either of the collimator configurations included with the ISOCS shield assembly. Additional templates will be added as they are developed and, for applications with special requirements, custom templates can be provided.

The standard ISOCS geometries and typical applications for each are:

Simple Box

A basic rectangular carton or waste shipping container as shown in Figure 6; a truck filled with scrap iron, or even a small building.

Complex Box

The same as the Simple Box, but with a more complex sample matrix. It includes the ability to distribute the contamination across as many as four layers of material and/or to place an additional concentrated source anywhere in the container. Ideal for use in "What If?" analyses of non-uniform distribution in waste assay containers.

Simple Cylinder

A basic barrel, tank, or drum, as shown in Figure 7. In an emergency, it could also be used for a quick whole body contamination count.

Complex Cylinder

The same as the Simple Cylinder, but with a more complex sample matrix. It includes the ability to distribute the contamination across as many as four layers of material and to place an additional concentrated source anywhere in the container. Ideal for use in "What If?" analyses of non-uniformity in barrels and drums.

Pipe

A pipe, empty or full, including material that has plated out or built up on the inner walls, as shown in Figure 8.

Circular Plane

The end of a barrel or tank, the bottom of a bottle containing a sample, or a filter cartridge. This would also be used for *in situ* measurements of ground. The radioactivity can be distributed in any manner in up to ten layers of sources/absorbers.

Rectangular Plane

A floor, wall, or ceiling, or soil *in situ*, as shown in Figures 9 and 10. The template allows for surface contamination as well as up to ten layers of internal contamination behind an absorber such as paint, paneling, or a floor covering.

Well or Marinelli Beaker

Used for well logging applications, or for standard Marinelli beakers.

Sphere

Internally contaminated spherical objects, like large pipe valves.

Using ISOCS for *In Situ* Assays

To illustrate how ISOCS is used, several typical applications will be briefly discussed. The general procedure is the same for each, with the differences being in the type and number of physical sample parameters that must be measured.

The basic procedure is as follows:

1. The needed shield components, if any, are fitted to the detector.
2. The detector is aimed at the sample, using the built-in laser as a positioning aid.
3. A sample count is performed using the simple fill-in-the-blank PROcount procedures.
4. The necessary physical sample measurements are taken.
5. An ISOCS calibration is performed, using the appropriate geometry template and the sample measurements, as shown in Figure 11.
6. The spectrum collected in Step 3 is analyzed using the calibration results from Step 5.

In the sections which follow the specific steps required for several common sample types will be described.

Soil or Floor Assay

Since this is the most traditional of *in situ* assays, it will be used for the first example. These assays, as well as those for walls and ceilings, are normally based upon the Circular Plane or Rectangular Plane template shown in Figure 12. The procedure is as follows:



Figure 6
Waste Containers.

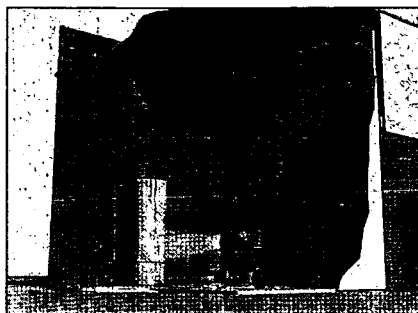


Figure 7
Tanks and Drums.



Figure 8
Pipes.



Figure 9
Soil or Floors.



Figure 10
Walls.

1. Fit any needed shield and collimator to the detector.
2. Position the detector vertically on its stand, looking downward at and perpendicular to the soil or floor.
3. Perform the count.
4. Measure and record:
 - a. The distance from the detector to the surface (Item 14.1 in Figure 12. If the detector is *not* perpendicular to the surface and *not* aimed at the center of the object, you need the other 14.2-5 measurements.)

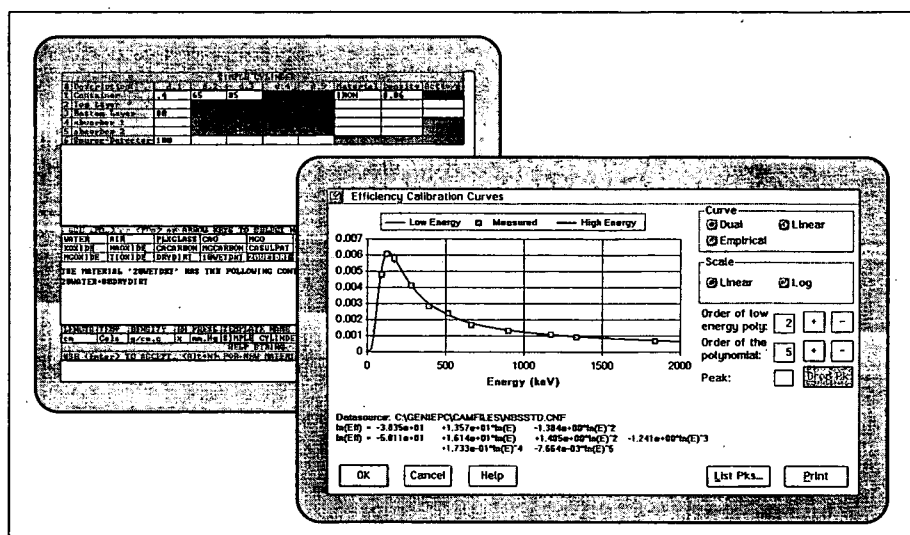


Figure 11
Using ISOCS for Efficiency Calibration.

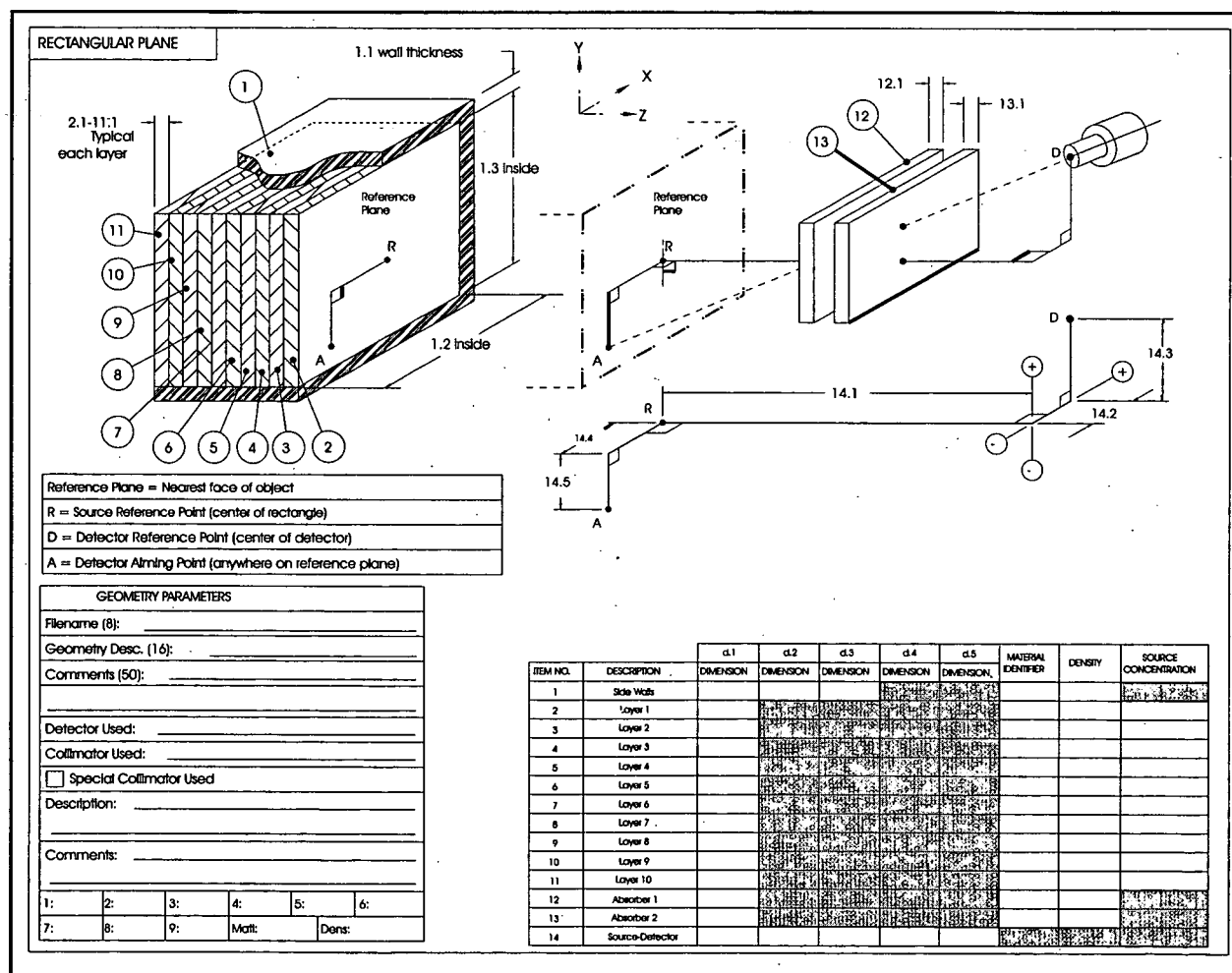


Figure 12
The geometry for a floor, wall, or ceiling.

- b. The size of the section being assayed. (Items 1.2 and 1.3. If a general assay of a large open area is being done, just use a large value, like 20 m.).
- c. If the contamination is under a surface such as in a paved parking lot, record the thickness, composition, and density. Each of the ten layers can be either sources or attenuators. For attenuators, enter 0 for the relative concentration.
- d. The thickness, composition, density, and relative concentration of each radioactivity layer.

Once the count is complete, you have all of the data that is needed. You can go on to count the next sample and perform the assay later, or complete it now if you wish. In either case, the process is:

5. Launch ISOCS Calibration from PROcount, as shown in Figure 11.
6. Select the Detector and Collimator, if any, that were used when the count was made. When you do that, the appropriate physical parameters for those devices are automatically loaded.
7. Select the Rectangular Plane template and enter the physical data that was collected.
8. Do the calibration, and use it for the analysis of the sample spectrum.

In a few seconds you'll have the completed qualitative and quantitative results.

But what if...?

But what if there are several different contaminated layers of soil? Or a layer of asphalt on top of the concrete that is covering the contaminated soil? This is where the other parameters in the geometry template come into use.

Referring to Figure 12, items 2 through 11 represent ten different layers of material. For any or all of them you can enter a thickness (assumed or measured), the material, and density, and the relative concentration of each layer [absorbers have 0 concentration]. After entering the desired "What if..." assumptions, re-run the ISOCS calibration, analyze the sample spectrum again, and you can immediately see the results of these new assumptions. This type of analysis can be used to define the boundary conditions for each measurement.

Assay of a Pipe

Next we'll take a look at the procedure used for the *in situ* assay of a contaminated pipe. The basic acquisition, calibration, and analysis process is essentially the same as the one for a soil count, with the differences related to the types of physical parameters that must be recorded.

Figure 13 shows the basic parameters of the Pipe template. These are:

1. The dimensions of the pipe, including the wall thickness, diameter, and the length on either side of the detector's aiming point, as indicated on the pipe by the built-in laser pointer.
2. The dimensions of any material that may have been plated onto the wall of the pipe.
3. The dimensions of any material that is contained in the pipe. Note item 3.2, which allows you to offset the center of this activity, treating it as a precipitate layer or partially filled pipe. Angle 3.5 allows this to be on the bottom portion of a horizontal pipe.

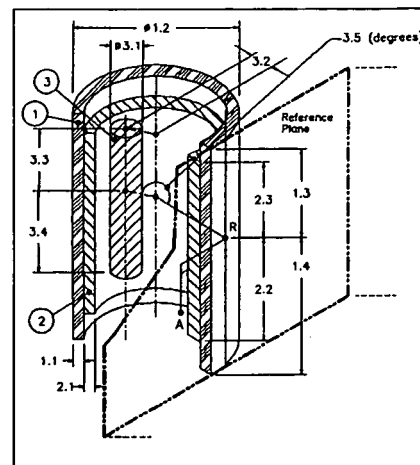


Figure 13
The geometry for a pipe.

For all of three of these you can also specify a material and density. Like all of the ISOCS templates, it also includes the ability to specify up to two layers of an absorber between the pipe and the detector and has a provision for entering the offset distances should it not be possible to have the detector perpendicular to the sample when the count is performed.

Traditional Sample Assay

The last example, shown in Figure 14, is the ISOCS detector and shield configured for counting a sample in a bottle or other similar container. You'll note that it combines both the 5 cm (2 inch) and 2.5 cm (1 inch) shield assemblies to yield a counting chamber that shields both the detector and the sample. The end cap at the top of the chamber is also part of the 2.5 cm shield kit. For counting dirt or liquid, just remove the collimator and top shield section. Place the dirt in a large Marinelli Beaker and put it over the top of the detector. The dirt/liquid is now both a sample and a shield.

The geometry template used for this application depends upon the shape and nature of the sample, with the Circular Plane template being the logical choice for bottles and filter cartridges. This template is identical to the Rectangular Plane template used for the Soil Analysis example except for its shape.

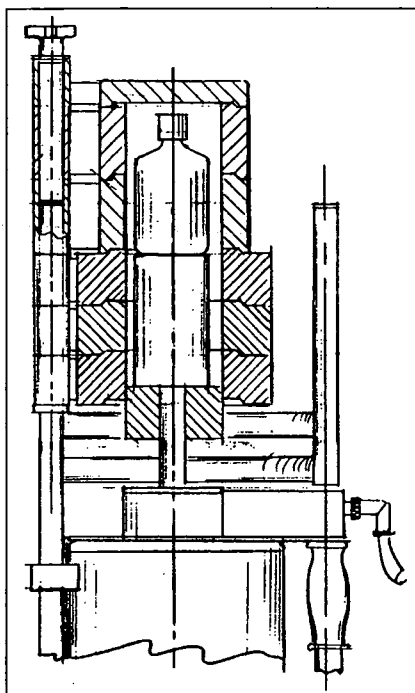


Figure 14
The ISOCS Detector & Shield set up for sample assay.

Complete details on this template, or any of the others currently supplied with ISOCS, can be found in the *ISOCS Calibration Software* specification sheet.

Additional Information

Additional information on ISOCS, its hardware and software components, and its applications may be found in the following publications, all of which are available from Canberra:

Specification Sheets

- Model ISOXSHLD ISOCS Shield System
- Model ISOXSW ISOCS Calibration Software for Genie-PC or Model ISOXG2K for Genie-2000
- InSpector Portable Spectroscopy Workstation
- Model S400/S402/S404 Genie-PC or Model S500/S502/S504 Genie-2000 Basic Spectroscopy Software

- Model S401C Genie-PC or S501C Genie-2000 Gamma Analysis Software
- Model S405C Genie-PC or S505C Genie-2000 QA Software
- Model S406C Genie-PC or S506C Genie-2000 Interactive Peak Fit software
- Model S403 PROcount-PC or S503 Genie-2000 PROcount Counting Procedure Software

Publications

For reprints of these papers, contact Canberra Customer Support at 1-800-255-6370 or email: customersupport@canberra.com.

- *Validation of the MCNP Monte Carlo Code for Germanium Detector Gamma Efficiency Calibrations*. F. Bronson, L. Wang. 1996.
- *Mathematical Calibration of Ge Detectors And The Instruments That Use Them*. F. Bronson, B. Young. 1997.
- *ISOCS Mathematical Calibration Software For Germanium Gamma Spectroscopy of Small and Large Objects*. F. Bronson, B. Young, V. Atraskevich. 1997.
- *ISOCS, a Laboratory Quality Ge Gamma Spectroscopy System That You Can Take to the Source for Immediate High Quality Results*. F. Bronson. 1997.
- *ISOCS (In Situ Object Counting System) Portable Gamma Spectroscopy Instrument, Chicago Pile 5 (CP-5) Research Reactor Large-Scale Demonstration Project*. L. Booth. 1998.
- *Nuclear Instrumentation Tools for Lower Cost and Higher Reliability Decommissioning of Buildings and Grounds*, F. Bronson. 1996.
- *Ge Gamma Spectroscopy Characterization Tools for Contaminated Materials in Buildings, Boxes and Dirt*. F. Bronson. 1996.

- *In Situ Gamma Spectroscopy for Assessment of Contaminants in Soil*. L. Booth, D. Groff, F. Bronson. 1996.

Configuration and Ordering Information

A typical ISOCS system consists of the following items. Consult Canberra for additional configuration information, available options, and pricing.

Detector

SIZE: As appropriate for the job.
For general purposes, the GC4020 is a good choice.

TYPE: Coaxial, LEGe, REGe, or XtRa as appropriate.

DEWAR: Model 7935-2 MAC or Model 7935-5 Big MAC.

RDC: Remote Detector Chamber option strongly recommended.

Shield

Model ISOXSHLD for the complete 25 mm and 50 mm set.

Spectroscopy Hardware

Model 1200 InSpector MCA.

Software

Model S401C Genie-PC or S501C Genie-2000 Gamma Analysis Option.

Model S404C Genie-PC or S504C Genie-2000 Basic Spectroscopy Software.

Model S405C Genie-PC or S505C Genie-2000 Quality Assurance.

Model ISOXSW Calibration Software and the characterization of one detector ordered at the same time. Extra charge for Canberra detectors previously ordered and for other vendor's detectors.

Computer

IBM or compatible Laptop, with Windows/95 or OS-2/2. Consult Canberra for type currently recommended.

Recommended Options

Model 702 Carrying Case for Detector, InSpector, PC, and D-2 fill device.

Model D-2 Portable detector LN filling device.

Model 2324 ^{137}Cs and ^{60}Co uncalibrated QA daily field check source.

Model S406C Genie-PC or S506C Genie-2000 Interactive Peak Fit software.

Model SU-455-3IN Environmental *In situ* Measurements Using the InSpector, three day course in Meriden for one person. On-site course are also available.

In Situ Gamma Spectroscopy Can Save You Both Time and Money.

In situ measurements will rarely be the complete solution, but for many cases it can greatly reduce the number and cost of gross [dose/rate/countrate] field measurements, and number of samples for laboratory measurements. With ISOCS, these field measurements are now easy to do. ISOCS should be added to the selection of tools available for field and emergency measurements.

In situ measurements using Ge detectors do not address beta emitters and may not fully address low levels

of alpha emitters. But, where other information is known (process knowledge, laboratory measurements of a few samples after radiochemistry, etc.) useful correlation ratios may be established and verified with gamma spectroscopy.

In the section which follows are some examples of where we believe having ISOCS as part of your radiological tool kit would be both useful and cost-effective. Is your application there? If it is, contact your local Canberra office to learn more about the time and cost savings offered by ISOCS.

Just a Few of the Many Applications That Can Benefit from ISOCS...

Environmental Monitoring Programs Around Nuclear Sites

- Measuring natural radioactivity when selecting new monitoring locations.
- Periodic measurements at fixed locations to identify long term trends or confirm the absence of long term low level deposition.
- Measurement of depositions at non-standard measurement locations to prove no unmonitored releases.
- Emergency response measurements:
 - Plume measurements with collimated detector aimed at sky.
 - Ground deposition measurements.
 - Field vegetation and water measurements.
 - Field gamma spectroscopy on air particulate and iodine cartridge samples.

Public Health Measurements

- Measurement of grounds and buildings of suspected contaminated areas. Immediate results feedback is better than lab data several months later.

Environmental Monitoring Around Accelerator Sites

- Background: Accelerators generate unusual activation products in air, soil, concrete, etc. They are commonly short half-life elements, so laboratory sample analysis is more difficult.
- Measurement of airborne plumes to identify nuclides.
- Measurement of soil and concrete to identify/quantify induced activity.



HP Measurements in Normally Operating Nuclear Facilities

- Check for total contamination (not just removable contamination). Aim collimated detector at suspect area (object, wall, ceiling).
- Check large areas for contamination (smears or hand probes just measure where the detector/smear is, if the contamination is not uniform, it could be missed). Aim collimated detector at suspect area (object, wall, ceiling).
- Check for unexpected contamination. A single measurement in center of room can prove that floors/walls/ceilings have not become contaminated, and that exposed sources are not in the room.
- Determine activity inside pipes/tanks without sampling. This could be easier and safer. And it could be more accurate if the sampling is not representative.
- Check for abnormal process operation. Take routine measurements at standard locations of piping, ventilation exhausts, etc. to monitor the rate of internal contamination buildup.

- Identifications of nuclides present to confirm dose rate conversion factors [especially if using sensitive but non-linear gross counting probes] and appropriate protection response [radiotoxicity is dependent upon the radionuclide].
- Identification of nuclides present after abnormal gross/dose rate survey indication.
- *In vivo* measurements of thyroid activity. WBC measurements where higher detection levels are acceptable.

Environmental Remediation Measurements

- For surface or near-surface measurements, much less expensive than sampling and laboratory measurements.
- Field results allow new measurements to be taken immediately to fill in data gaps or to resolve questionable data.
- Multiple measurements on grid pattern can prove the absence of contamination and locate it if present. Detector heights determines spatial sensitivity. Large detector-ground separations measure larger areas with fewer measurements, or with better accuracy.
- Collimators can be used to reduce influence of adjacent sources or to define the spatial area of a measurement.
- For subsurface measurements, drilling holes and taking samples is very expensive. Instead, line the holes with plastic pipe, and take measurements at various depths down the hole.
- For measurement of sludge/mud at bottom of lakes/rivers, sampling is very difficult. Use Ge detector in waterproof housing (e.g. Canberra Submarine waterproof detector housing).

Decontamination and Decommissioning of Buildings

- Preliminary scoping surveys to see if something is there or not. Unshielded detector in center of room is very sensitive to removable, fixed, and buried contamination.
- Evaluation of surface area contamination. Collimated detectors aimed at large wall/floor/ceiling areas can quickly prove that contamination is present/absent and to quantify it.
- Looking for buried contamination (or proving it to be absent). This could be contamination covered over by paint or new concrete layers, or in pipes hidden inside walls or under floors. Sampling will be very difficult, and is likely to miss contamination.
- Estimation of depth of contamination by looking at peak ratios. Where this is possible, this technique can be much more accurate and much less expensive than taking samples for laboratory analysis.
- To replace/reduce sampling and subsequent laboratory analysis:
 - Instead of slicing concrete cores and lab analyses, drill hole and insert detector (perhaps with side collimator for fine depth information).
 - Instead of scabbing off surface layers of concrete, place collimated detector over area.
 - Instead of drilling out samples of steel/concrete/etc. to look for neutron activation, place collimated detector over area.

Maintenance Operations in Nuclear Facilities

- Identify nuclides present and activity present inside valve/pipe/tank before opening. This is generally easier and safer and more accurate than sampling. Knowing the activity allows the proper amount of radiological protection to be applied. Too little *and* too much can likely increase the dose.
- Evaluate residual activity in tanks/pipes. Plateout is difficult to sample.
- Evaluate the depth of contamination by evaluation of energy line ratios.
- Estimate location of radioactivity in/on complex objects by use of multiple measurements from different angles.



Radioactive Waste Measurements at Generation Sites

- For the large user, automatic waste box/drum assay systems designed specifically for this task are available from Canberra. For the small user, an *in situ* system can be used for drums and boxes, although the count times may be longer and more labor would be required.
- For unusual shaped objects that do not fit into standard waste assay systems, use the *in situ* system.
- Perform periodic measurements with nuclide specific results, to verify that the waste stream characterization is as expected. This is important of other instruments that are not nuclide specific (dose rate, gross counting) are used to generate shipping and disposal records.

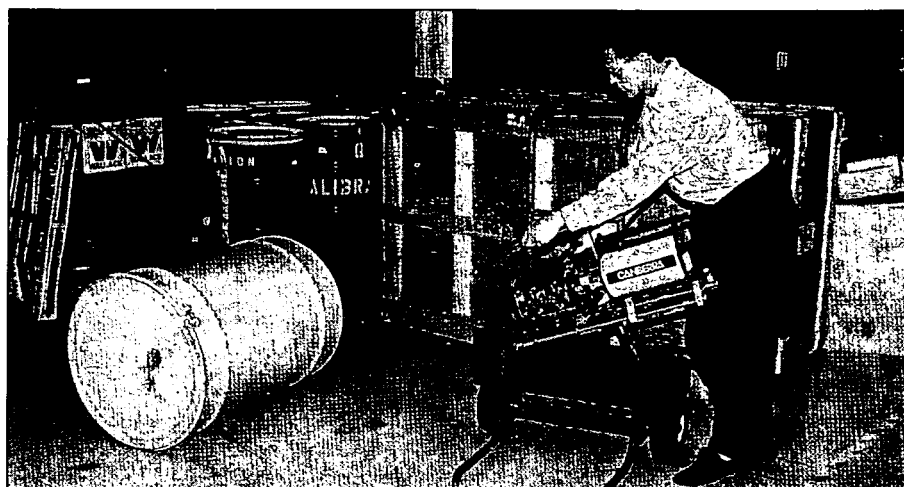
Radioactive Waste Measurements at Disposal Sites

- Shippers commonly estimate activity, and generally estimate high because it is conservative. However this "excess" radioactivity could fill up a disposal site too early.

- Periodic verification of shippers declared activity. Test a few random containers. Measurement of the entire container is more accurate than taking samples of non-homogeneous waste. For large numbers of measurements, consider the Canberra Box counter (just a large number of shielded *in situ* measurements).
- Field inspections of waste generator activities.

Tool kit for Routine and Emergency Response for Radiological Health Authorities

- Quick field response to transportation accidents. Has anything spilled? What is it? How much is it? Where do we take samples? Is any quick action required?
- Rapid response from alarms on scrap steel monitors (sample taking is very difficult). What is it? How much is it?
- Rapid response from alarms on gross counters at country border inspection points. What is it? How much is it?
- Independent verification of users' environmental monitoring program via ground deposition measurements, and independent sample measurements.
- Measurement of short lived nuclides in environmental samples or effluents from hospitals, accelerators, reactors, etc.
- Independent verification of users laboratory measurement program (more rapid response than lab measurements, makes short lived nuclide measurements possible).
- Portable gamma spectroscopy laboratory-in-a-box, when combined with portable shield Quantitative measurements can be performed on air particulate samples, gas samples, iodine samples, water samples, vegetation samples, dirt samples, etc.
- Emergency and/or very portable *in vivo* counter. Take to hospitals to measure injured contaminated people. Can be used for higher level measurements where too much radioactivity prevents normal WBC use. Thyroid measurements in universities or hospitals. Retained activity in nuclear medicine tests. Count groups of people at one time to prove that contamination not present as emergency response triage tool.
- *In vivo* measurements of thyroid activity. WBC measurements where higher detection levels are acceptable.



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